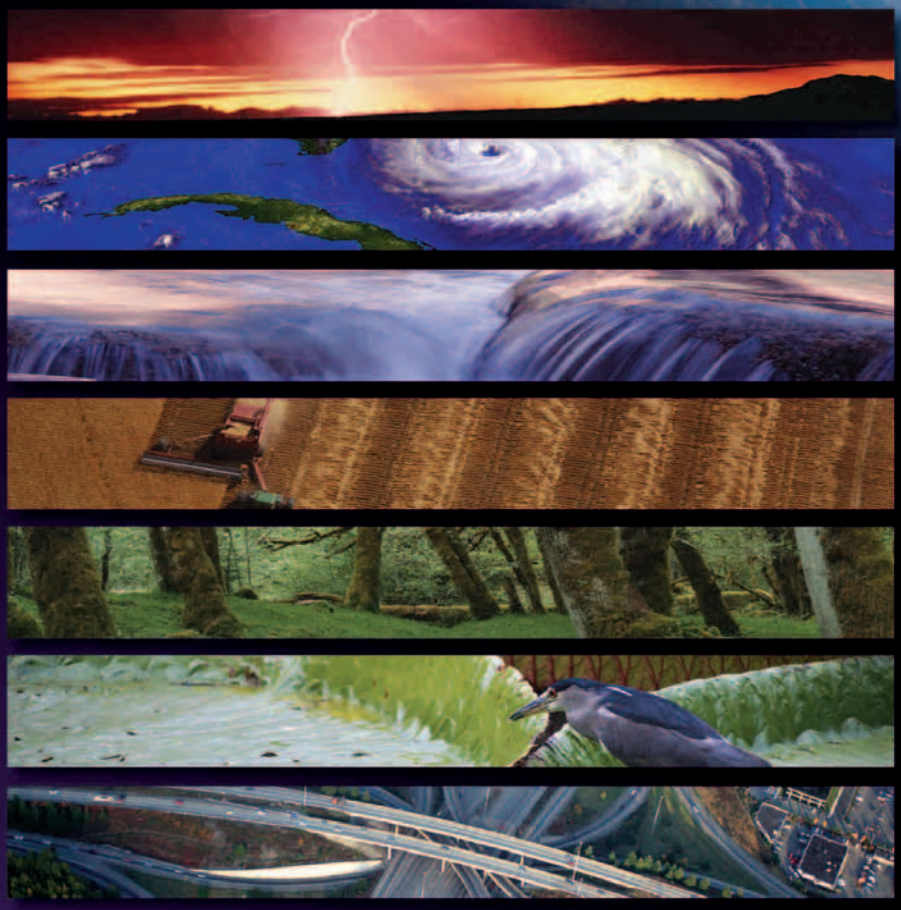
OUR CHANGING PLANET

The U.S. Climate Change Science Program for Fiscal Year 2006



A Report by the
Climate Change Science Program and
the Subcommittee on Global Change Research

A Supplement to the President's Budget for Fiscal Year 2006

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This document describes the U.S. Climate Change Science Program (CCSP) for FY 2006. It provides a summary of the achievements of the program, an analysis of the progress made, and budgetary information. It thereby responds to the annual reporting requirements of the U.S. Global Change Research Act of 1990 (section 107, P. L. 101-606). It does not express any regulatory policies of the United States or any of its agencies, or make any findings of fact that could serve as predicates for regulatory action. Agencies must comply with required statutory and regulatory processes before they could rely on any statements in this document or by the CCSP as a basis for regulatory action.

OUR CHANGING PLANET

The U.S. Climate Change Science Program for Fiscal Year 2006

A Report by
the Climate Change Science Program and
the Subcommittee on Global Change Research

A Supplement to the President's Budget for Fiscal Year 2006

November 2005

Members of Congress:

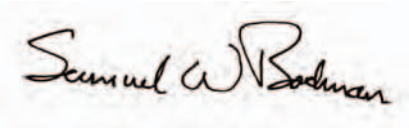
We are pleased to transmit a copy of *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2006*. The report describes the activities and plans of the Climate Change Science Program (CCSP), which incorporates the U.S. Global Change Research Program, established under the Global Change Research Act of 1990, and the Climate Change Research Initiative, established by the President in 2001. CCSP coordinates and integrates scientific research on climate and global change supported by 13 participating departments and agencies of the U.S. Government.

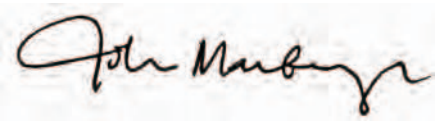
This FY 2006 edition of *Our Changing Planet* highlights recent advances supported by CCSP participating agencies in each of the program's research and observational elements, as called for in the *Strategic Plan for the U.S. Climate Change Science Program* released in July 2003. It describes a wide range of new and emerging observational capabilities which, combined with the program's other analytical work, are leading to remarkable advances in understanding the underlying processes responsible for climate variability and change.

The document illustrates advances in U.S. modeling capabilities to represent past, present, and potential future changes in the physical and biological dimensions of the Earth system. The report also highlights progress being made to explore the uses and limitations of evolving knowledge to manage risks and opportunities related to climate variability and change. The final chapter documents the program's numerous current activities to promote cooperation between the U.S. scientific community and its worldwide counterparts.

The document also outlines how CCSP plans to continue implementation of the *CCSP Strategic Plan* during FY 2006. A significant emphasis in 2006 will be continued work on the production of 21 scientific synthesis and assessment reports on a wide range of topics to support informed discussion of climate change by decisionmakers and the public.

CCSP is committed to its mission to facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication. We thank the CCSP participating agencies for their close cooperation, and we look forward to working with Congress in the continued development of this important program.





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THE U.S. CLIMATE CHANGE SCIENCE PROGRAM

THE U.S. CLIMATE CHANGE SCIENCE PROGRAM FOR FY 2006

Climate influences the environment, natural resources, the economy, and other aspects of life on Earth. The Climate Change Science Program (CCSP) was established in 2002 to empower the Nation and the global community with the science-based knowledge to manage risks and opportunities of change in the climate and related environmental systems. CCSP incorporates and integrates the U.S. Global Change Research Program (USGCRP) with the Administration's U.S. Climate Change Research Initiative (CCRI).

The USGCRP was established by the Global Change Research Act of 1990 to enhance understanding of natural and human-induced changes in the Earth's global environmental system; to monitor, understand, and predict global change; and to provide a sound scientific basis for national and international decisionmaking.

While the Earth has always undergone changes in its climate and environment, the potential importance of human contributions to change on a global scale has emerged comparatively recently. The importance of the issues and the unique role that science can play in informing society's responses give rise to CCSP's guiding vision.

CCSP GUIDING VISION

A nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems.

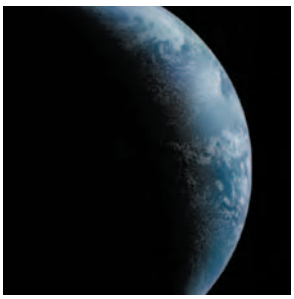
The core precept that motivates CCSP is that the best possible scientific knowledge should be the foundation for the information required to manage climate variability and change and related aspects of global change.

CCSP MISSION

Facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication.

Research conducted through CCSP is building on scientific advances of the last few decades and is deepening our understanding of the interplay of natural and human-caused forces. CCSP is developing information to facilitate comparative analysis of different approaches to adaptation to and mitigation of climate change. CCSP also promotes capacity development among scientists and information users – both in the developed and the developing world – to address the interactions between climate change, society, and the environment.

Integrating Climate and Global Change Research



CCSP integrates the USGCRP, which was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606, 104 Stat. 3096-3104), and the CCRI, which was established by President Bush in 2001, to improve understanding of uncertainties in climate science, expand global observing systems, develop science-based resources to support policymaking and resource management, and communicate findings broadly among scientific and stakeholder communities. Thirteen departments and agencies of the U.S. Government participate in CCSP, including:

- Department of Agriculture (USDA)
- Department of Commerce / National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior / U.S. Geological Survey (DOI/USGS)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

DEFINITION OF KEY TERMS

Adaptation
Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

Climate
The statistical description of the mean and variability of relevant measures of the atmosphere-ocean system over periods of time ranging from weeks to thousands or millions of years.

Climate Change
A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcing, including changes in solar radiation and volcanic eruptions, or persistent human-induced changes in atmospheric composition or in land use.

Climate Feedback
An interaction among processes in the climate system in which a change in one process triggers a secondary process that influences the first one. A positive feedback intensifies the change in the original process, and a negative feedback reduces it.

Climate System
The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface, the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and human-induced forcings such as the changing composition of the atmosphere and land-use change.

Climate Variability
Variations in the mean state and other statistics of climatic features on temporal and spatial scales beyond those of individual weather events. These often are due to internal processes within the climate system. Examples of cyclical forms of climate variability include the El Niño Southern Oscillation, the North Atlantic Oscillation, and the Pacific Decadal Oscillation.

Decision-Support Resources
The set of observations, analyses, interdisciplinary research products, communication mechanisms, and operational services that provide timely and useful information to address questions confronting policymakers, resource managers, and other users.

Global Change
Changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life (from the Global Change Research Act of 1990, PL 101-606).

Mitigation
An intervention to reduce the human-induced factors that contribute to climate change. This could include approaches devised to reduce emissions of greenhouse gases to the atmosphere; to enhance their removal from the atmosphere through storage in geological formations, soils, biomass, or the ocean; or to alter incoming solar radiation through several "geo-engineering" options.

Observations
Standardized measurements (either continuing or episodic) of variables in climate and related systems.

Prediction
A probabilistic description or forecast of a future climate outcome based on observations of past and current climatological conditions and quantitative models of climate processes (e.g., a prediction of an El Niño event).

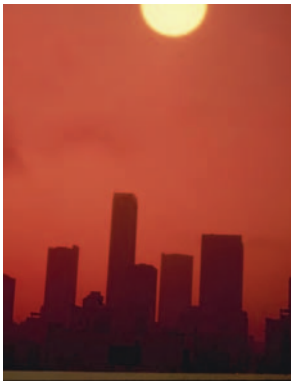
Projection
A description of the response of the climate system to an assumed level of future radiative forcing. Changes in radiative forcing may be due to either natural sources (e.g., volcanic emissions) or human-induced factors (e.g., emissions of greenhouse gases and aerosols, or changes in land use and land cover). Climate "projections" are distinguished from climate "predictions" in order to emphasize that climate projections depend on scenarios of future socioeconomic, technological, and policy developments that may or may not be realized.

Weather
The specific condition of the atmosphere at a particular place and time, measured in terms of variables such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

In addition, the Executive Office of the President and other related programs have designated liaisons who participate on the CCSP Interagency Committee, including:

- Office of Science and Technology Policy (OSTP)
- Council on Environmental Quality (CEQ)
- Office of Management and Budget (OMB)
- Climate Change Technology Program (CCTP)
- Office of the Federal Coordinator for Meteorology (OFCM)
- National Institute of Standards and Technology (NIST).

Appendix A, "The Climate Change Science Program Participating Agencies," contains information about the specific missions and roles of each agency participating in CCSP. Appendix B, "Climate Change Science Program FY 2006 Budget Tables," in the insert pocket, contains budgetary analyses of the program grouped by agency as well as a program-wide interagency cross-cut grouped by the strategic goals and research elements of CCSP as described in the *Strategic Plan for the U.S. Climate Change Research Program* published in July 2003.

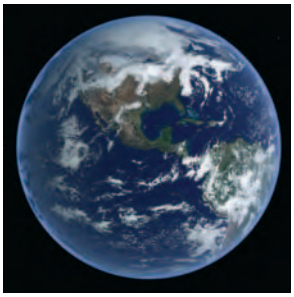


As a multi-agency program, CCSP harnesses the unique approaches and missions of its participating agencies to encourage research that leads to expanded and new results. A significant challenge that arises from working across many agencies is integrating climate and global change research to develop a comprehensive view of climate change and its potential significance. CCSP adds value to the individual Earth and climate science missions of its 13 participating agencies and their national and international partners by coordinating research and facilitating integration of information to achieve results that no single agency, or small group of agencies, could attain.

CCSP relies not only on the agency programs stated in its budget cross-cut, but also on agency activities that are not formally included in the CCSP budget. Examples of these directly related activities are NOAA's long-term surface, balloon, and satellite-based meteorological observations; surface hydrological and satellite land-cover observations from USGS; and future satellite measurement programs including the tri-agency (NOAA, DOD, NASA) National Polar-Orbiting Operational Environmental Satellite System (NPOESS) and the planned multi-program implementation of continuity of Landsat observations. Without input from activities such as these, CCSP would be unable to fulfill its mission.

CCSP also relies on and provides input to other major interagency programs that observe and study particular aspects of the environment and associated human activities.

Foremost among these is the Climate Change Technology Program, which develops and studies technological options for responding to climate change. A key observational linkage is with the U.S. Integrated Earth Observation System, which is part of the international Global Earth Observation System of Systems. CCSP is also linked to another set of activities articulated in the Ocean Action Plan recently released by the Cabinet-level Committee on Ocean Policy. Connections to programs such as these allow CCSP and its partners to leverage their resources to derive mutual benefits from advances in any one program.



Coordinating Research Elements

Efforts to foster integration occur on many levels. One is improving coordination of scientific research and the flow of information through interdisciplinary and interagency working groups focused on each of seven main "research elements" of the program plus a number of cross-cutting activities or themes. CCSP's research elements include atmospheric composition, climate variability and change, the global water cycle, land-use and land-cover change, the global carbon cycle, ecosystems, and human contributions and responses to environmental change. For each of the research elements, recent highlights and program plans for FY 2006 are described in subsequent chapters of this report. The budget tables appendix contains information on the CCSP budget by research element. This budget cross-cut illustrates integrative management of the program that starts from research-driven requirements and extends to coordinated planning to distribute and integrate work efficiently across CCSP's participating agencies.

Integration through Products Addressing CCSP Goals

CCSP seeks to integrate basic research in a variety of products related to the five goals of the program. These goals span the full range of climate-related issues, including natural climate conditions and variability; forces that influence climate, including cycles and processes that affect atmospheric concentrations of greenhouse gases and aerosols; climate responses; consequences for ecosystems, society, and the economy; and application of knowledge to decisionmaking. This comprehensive characterization provides a useful organizing scheme for examining key climate change issues. The accompanying box identifies the program's goals and examples of key research focus areas.

For the first time, the FY 2006 edition of *Our Changing Planet* provides a budget cross-cut of the program organized by CCSP goal. This new analysis of the program is introduced in the next section of this chapter and is contained in the budget tables appendix.

CCSP GOALS AND EXAMPLES OF KEY RESEARCH FOCUS AREAS

Goal 1: Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

- Better understand the natural long-term cycles in climate (e.g., Pacific Decadal Oscillation, North Atlantic Oscillation).
- Improve and harness the capability to forecast El Niño and La Niña events and other seasonal-to-interannual cycles of variability.
- Sharpen understanding of climate extremes through improved observations, analyses, and modeling, and determine whether any changes in their frequency or intensity lie outside the range of natural variability.
- Increase confidence in the understanding of how and why climate has changed.
- Expand observations and data/information system capabilities.

Goal 2: Improve quantification of the forces bringing about changes in the Earth's climate and related systems.

- Reduce uncertainty about the sources and sinks of greenhouse gases, emissions of aerosols and their precursors, and their climate effects.
- Monitor recovery of the ozone layer and improve understanding of the interactions among climate change, ozone depletion, and other atmospheric processes.
- Increase knowledge of the interactions among pollutant emissions, long-range atmospheric transport, climate change, and air quality management.
- Develop information on the carbon cycle, land cover and use, and biological/ecological processes by helping to quantify net emissions of carbon dioxide, methane, and other greenhouse gases, thereby improving the evaluation of carbon sequestration strategies and alternative response options.
- Improve capabilities to develop and apply emissions and related scenarios for conducting "If…, then…" analyses in cooperation with CCTP.

Goal 3: Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

- Improve characterization of the circulation of the atmosphere and oceans and their interactions through fluxes of energy and materials.
- Improve understanding of key "feedbacks" including changes in the amount and distribution of water vapor, extent of ice and the Earth's reflectivity, cloud properties, and biological and ecological systems.
- Increase understanding of the conditions that could give rise to events such as rapid changes in ocean circulation owing to changes in temperature and salinity gradients.
- Accelerate incorporation of improved knowledge of climate processes and feedbacks into climate models to reduce uncertainty about climate sensitivity (i.e., response to radiative forcing), projected climate changes, and other related conditions.
- Improve national capacity to develop and apply climate models.

Goal 4: Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

- Improve knowledge of the sensitivity of ecosystems and economic sectors to global climate variability and change.
- Identify and provide scientific inputs for evaluating adaptation options, in cooperation with mission-oriented agencies and other resource managers.
- Improve understanding of how changes in ecosystems (including managed ecosystems such as croplands) and human infrastructure interact over long periods of time.

Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

- Support informed public discussion of issues of particular importance to U.S. decisions by conducting research and providing scientific synthesis and assessment products.
- Support adaptive management and planning for resources and physical infrastructure affected by climate variability and change; build new partnerships with public and private sector entities that can benefit both research and decisions.
- Support policymaking by conducting comparative analyses and evaluations of the socioeconomic and environmental consequences of response options.

CCSP products include synthesis and assessment reports (see chapter on "Decision-Support Resources Development and Related Research on Human Contributions and Responses"), as well as numerous scientific deliverables that are described in the *Strategic Plan for the U.S. Climate Change Research Program*, issued in July 2003. The research element chapters of this report include updates on the preparation of CCSP research products, milestones, and activities, with reference to the research focus areas for each goal. These products and activities integrate research from many disciplines conducted or supported across the participating agencies.

Integrating research and observational approaches across disciplinary boundaries is essential for understanding how the Earth system functions and how it will change in response to future forcing. This is due to the interconnectedness among components of the Earth system, which often relate to each other through feedback loops. Interdisciplinary interactions in CCSP are scaled to the nature of the problem. In some cases, the necessary science may be conducted within a small set of disciplines, such as those required to improve understanding of cloud microphysics. In other cases, highly interdisciplinary approaches are required, such as in the case of making projections about the future state of the Earth system and analyzing their implications. In the latter example, expertise ranging from the social sciences to atmospheric dynamics and chemistry to oceanography to the biological sciences is required.

Interdisciplinary research is only one aspect of the integration facilitated by CCSP. Integration in CCSP also refers to the steps being taken to create more seamless approaches between the theory, modeling, observations, and applications that are required to address the multiple scientific challenges being confronted by CCSP. Finally, integration in CCSP also refers to the enhancement of cooperation across agencies toward meeting the objectives articulated in the *CCSP Strategic Plan*.

The accompanying box provides one example of how different research elements may help address a key uncertainty. This example illustrates some of the key scientific issues within each of the CCSP research elements that need to be coordinated within the Global Carbon Cycle research element to improve future projections of atmospheric carbon dioxide (CO_2) levels.

Program Management

As described in the *CCSP Strategic Plan*, CCSP employs a management approach that integrates the planning and implementation of individual climate and global change research programs of the participating Federal agencies and departments to reduce overlaps, identify and fill programmatic gaps, and synthesize products and deliverables

INTEGRATING ACROSS RESEARCH ELEMENTS TO IMPROVE PROJECTIONS OF CARBON DIOXIDE CONCENTRATIONS

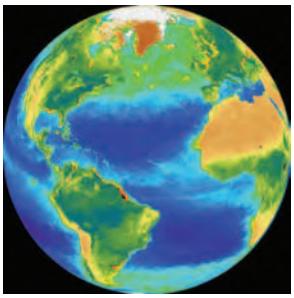
CCSP research on carbon dioxide (CO_2) is coordinated through its Global Carbon Cycle research element. The success of that research element's ability to improve projections of future CO_2 concentrations depends significantly on inputs from and coordination with all of the program's other research elements. This includes consolidating and improving understanding of past and current CO_2 concentrations; past, current, and future sources and magnitudes of emissions and sinks; processes that transport CO_2; processes that remove it from the atmosphere; and integrative modeling of these processes. A few examples are provided below of the types of scientific research from each CCSP research element that must be advanced and coordinated with the Global Carbon Cycle research element to improve projections of CO_2 concentrations.

- *Atmospheric Composition* – Although the measurement of the distribution of CO_2 and methane in the atmosphere is a major component of the CCSP Global Carbon Cycle research element, identifying and understanding sources and sinks of these gases is augmented by information on other atmospheric constituents such as carbon monoxide and other gases that can be used as tracers of anthropogenic or natural processes.
- *Climate Variability and Change* – The climate system circulates CO_2 from its source regions and distributes it around the globe. Climate also plays an important role in determining the uptake and release of CO_2 by the oceans and ecosystems through its effects on marine chemistry, photosynthesis, respiration, and decay. Improved estimates of current and projected climate conditions are essential to projecting future changes in CO_2 concentration.
- *Global Water Cycle* – Precipitation, humidity, and soil moisture play crucial roles in determining terrestrial uptake and release of CO_2 through their influence on vegetation. Runoff transports carbon from the land surface to the oceans. Understanding the interplay between the water and carbon cycles is vital to projecting future changes in both.
- *Land-Cover/Land-Use Change* – Some changes in land use (e.g., conversion from timber production to livestock grazing) are associated with net CO_2 emissions. Other changes in land use and management are associated with net CO_2 sequestration (e.g., changing from intensive tillage to no-till agriculture). Improved understanding of how land is used in different locations, as well as how land uses might change over time, is crucial to estimating current and projecting future emissions as well as future sequestration opportunities.
- *Ecosystems* – Widespread but subtle changes in ecosystem distribution and composition may lead to significant changes in the concentration of atmospheric CO_2 because such large amounts of carbon are exchanged in ecosystems through photosynthesis, respiration, decay, and disturbance. Advances in carbon cycle research depend upon improvements in understanding the effect of climate on ecosystems, including their projected rates of carbon uptake and release.
- *Human Contributions and Responses* – The main human processes responsible for changing the concentration of atmospheric CO_2 are fossil-fuel burning, deforestation, land-use change, and cement production. These processes have changed and will continue to change over time, hence must be considered in estimating current and projecting future emissions, as well as mitigating future climate change.

generated under the auspices of CCSP. Five mechanisms are used to achieve this management approach:

- *Executive Direction* – The Interagency Working Group on Climate Change Science and Technology and the CCSP Principals Committee are responsible for overall priority setting, program direction, management review, and accountability to deliver program goals.
- *Agency Implementation* – CCSP participating departments and agencies are responsible for conducting research, developing and operating observing systems, and producing CCSP-required products, often in collaboration with interagency working groups.

- *Interagency Planning and Implementation* – Several interagency working groups, including one for each CCSP research element, are responsible for coordinating planning and implementation to align agency programs with CCSP priorities.
- *External Guidance and Interaction* – External advisory groups and organizations, including the National Academies (see section below), provide external guidance, oversight, and interactions to ensure scientific excellence, credibility, and utility.
- *Program Support* – The CCSP Office provides staffing and day-to-day coordination of CCSP-wide program integration, strategic planning, product development, and communications.



Integrated Program Analysis

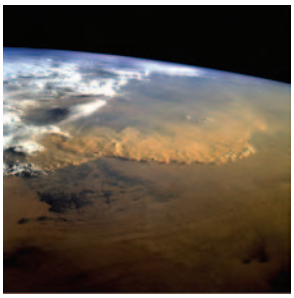
In a highly distributed program such as CCSP, it is often a challenge to develop and maintain a cohesive perspective, ensuring that key components or interactions of the integrated Earth system are not overlooked. To help address this challenge, the program has often turned to the National Academies for guidance. Two of the dozens of reports that have helped guide the program's activities are *Global Environmental Change: Research Pathways for the Next Decade* (NRC, 1999) and *Climate Change Science: An Analysis of Some Key Questions* (NRC, 2001). CCSP has recently requested that the National Research Council (NRC) establish a new committee to provide high-level integrated advice on the evolution of the program. This committee will provide independent annual reports on different aspects of the program, including:

- Strategic advice on program priorities and implementation strategy in the context of scientific and societal objectives, including the recommendation of high-priority program areas not previously supported.
- An evaluation of progress toward meeting the program's goals. This evaluation will build on the recommendations of the NRC Committee on Metrics for Global Change Research, and will offer advice to the program and the Nation on performance measurement systems (including non-quantitative measures) that can be used for multi-agency programs like CCSP.
- A strategic review of the program's decision-support activities in the context of the program's goals. The initial review will focus on the program's synthesis and assessment products, but also will examine other significant CCSP decision-support activities, including:
  - The adequacy of the overall portfolio of decision-support activities to meet the program's goals
  - The scientific and technical quality of the program's decision-support tools and products
  - The potential evolution of the program's decision-support activities over time to meet the program's goals.

When requested, the new committee will participate in the review of draft prospectuses for CCSP synthesis and assessment products, and will provide analysis associated with the interpretation of scientific findings in the products.

CCSP will continue to also rely on other mechanisms for scientific guidance and advice, including other NRC committees that focus on particular components of the climate system, scientific advisory groups that support individual agencies, scientific steering groups organized to coordinate different CCSP research elements, and open dialog with the domestic and international scientific and user communities interested in global change issues.

CCSP FY 2006 Priority Areas and New Initiatives



An important step in coordinating the CCSP budget for FY 2006 has been to align the agency climate programs with the goals and key research focus areas in the *CCSP Strategic Plan*, thus helping to ensure consistency. The emphasis is on ensuring alignment of current funding with a recommended list of priorities and identifying gaps that may occur, as well as identifying measurable milestones and deliverables that reflect accountability toward meeting program goals.

The current CCSP program is a high-priority selection of activities that merit continued support. However, new initiatives are required to move in directions identified in the *CCSP Strategic Plan*. CCSP must maintain key research activities, while encouraging innovation in a constrained budget environment. There is a need for continuing evolution of program priorities and activities through new initiatives, the competitive grant process within the agencies, and other evolutionary redirection reflecting new focus areas for high-priority research in climate science. The program aspires to refresh programs during each budget cycle such that over a 5-year period, approximately one-third of CCSP research activities will support new research directions. Recognizing that research and monitoring often involve long-term programs, the objective of refreshing one-third of program activities over a 5-year period represents a desired balance between program continuity and new program priorities.

CCSP focuses on nine priority themes to accelerate the delivery of critical science-based information in support of decisionmaking:

1) Reduce scientific uncertainties associated with aerosol distribution, properties, and radiative impacts
2) Analyze climate variability, sensitivity, and feedbacks
3) Enhance climate modeling systems

4) Reduce scientific uncertainties regarding the water cycle
5) Reduce scientific uncertainties regarding carbon sources and sinks
6) Conduct climate-ecosystems research
7) Improve decision-support capabilities
8) Enhance global climate observations
9) Improve communications between scientists and information users.

There is close alignment between these priority areas and the CCSP research elements described in the *CCSP Strategic Plan* and in this document. A number of ongoing CCSP-supported research projects do not fall within the priority themes identified above, but are essential for meeting the agreed objectives of the *CCSP Strategic Plan* (e.g., long-term monitoring efforts). The following examples highlight some of the topics included under each of these priority areas:

- *Reduce scientific uncertainties associated with aerosol distribution, properties, and radiative impacts* – CCSP will continue to explore the representation of climate forcing resulting from atmospheric aerosols. Examples of proposed activities include research on:
  - The radiative effects of aerosols and their impacts on climate
  - Aerosol-cloud-climate interactions and the relationship between aerosols and precipitation.
- *Analyze climate variability, sensitivity, and feedbacks* – CCSP will continue to extend understanding of climate variability, sensitivity, and feedbacks, including feedbacks from clouds, water vapor, atmospheric convection, ocean circulation, ice albedo, and vegetation. Some key activities are research projects that will:
  - Extend and improve predictions of the effects of ocean circulation and periodic natural fluctuations such as El Niño and solar activity on climate variability
  - Document and understand the observed trends and variability of climate extremes
  - Improve representation of cloud feedback processes in global climate models using results from satellite and *in situ* observations and results from process studies.
- *Enhance climate modeling systems* – The capabilities of climate and atmospheric composition models will be enhanced with some key efforts, such as:
  - Improving model representations of key physical processes including clouds, aerosols, and precipitation, as well as coupling of atmosphere, ocean, land, and vegetation processes
  - Increasing resolution of climate model simulations
  - Improving methods to assimilate observed climate data
  - Testing models against observations and defining requirements for observing systems to support forecasts and improve models.

  Many of these modeling efforts will require continuing increases in computer capacity as well as human capital.

- *Reduce scientific uncertainties regarding the water cycle* – CCSP seeks to improve the understanding of global and regional water cycles through specific activities, including:
  - Research utilizing improved observations and modeling of water cycle processes leading to closing the water budget on regional and global scales
  - Research on the interactions between the atmospheric, continental land surface/vegetation, oceanic, biogeochemical, and cryospheric processes involving the water cycle
  - Studies of the predictability of extreme events such as extended droughts or wet spells, and consequences of natural or anthropogenically influenced changes to the climatic regimes of the water cycle.
- *Reduce scientific uncertainties regarding carbon sources and sinks* – CCSP seeks to improve understanding of the global carbon cycle through targeted activities such as:
  - Research relating to the North American Carbon Program, which will reduce the uncertainty in estimates of the North American carbon budget
  - Research on terrestrial processes regulating carbon storage, which will improve estimates of carbon sequestration in terrestrial ecosystems
  - Conducting studies using model projections to help improve understanding of the range of future carbon dioxide emissions and scenarios.
- *Conduct climate-ecosystems research* – Key activities in climate-ecosystem research include studies of:
  - The relationship between observed ecosystem changes and climate change
  - Coastal response to sea-level change
  - The effects of warming, changes in precipitation, increasing atmospheric carbon dioxide concentration, and ultraviolet radiation on the structure and functioning of terrestrial and marine ecosystems.
- *Improve decision-support capabilities* – CCSP will develop and test resources to support planning, adaptive management, policymaking, and public discussion of changes in climate and related systems. A major focus area will be drafting the first set of CCSP synthesis and assessment products and the initial phases of work on the remaining products. Specific plans for enhanced decision-support resources include:
  - Developing decision-support tools to improve society's ability to plan and respond to climate variability and change
  - Conducting decision-support experiments and evaluations using seasonal-to-interannual forecasts and observational data.
- *Enhance global climate observations* – CCSP will continue to focus on the development of a comprehensive climate observing system in close collaboration with the U.S. Group on Earth Observations, which is coordinating the overall contributions of the United States to the Global Earth Observing System of Systems (GEOSS). Priority activities will address the development of an integrated

end-to-end observing system designed to minimize data gaps and maximize the utility of observing networks. Highlighted activities include:
  - Providing new paleoclimate products, such as annual- to decadal-scale maps of Arctic climate variability over the past 2,000 years
  - Developing and demonstrating new space-based observing capabilities to meet climate research requirements
  - Enhancing data and information management and distribution systems by developing and implementing new technologies.
- *Improve communications between scientists and information users* – CCSP will improve dialog with stakeholders through workshops, publications, and web sites. All of the CCSP agencies implement efforts in this area, which include:
  - Reporting relevant aspects of scientific findings
  - Disseminating results of CCSP activities
  - Making scientific information and products easily available in formats suitable to a diverse set of audiences, policymakers, and technical experts involved in adaptive management decisions.

Decision Support: Information to Support Policy and Adaptive Management Decisionmaking

CCSP sponsors and conducts research that is ultimately related to policy and adaptive management decisionmaking. CCSP's decision-support approach is guided by several general principles, including:
- Early and continuing involvement of stakeholders
- Explicit treatment of uncertainties
- Transparent public review of analysis questions, methods, and draft results
- Evaluation of lessons learned from ongoing and prior decision-support and assessment activities.

Synthesis and Assessment Products

CCSP is generating synthesis and assessment products to support informed discussion and decisionmaking on climate variability and change by policymakers, resource managers, stakeholders, the media, and the general public. More information about the products can be obtained from the CCSP web site <www.climatescience.gov>. These products will integrate research results focused on key issues and related questions frequently raised by decisionmakers. Current evaluations of the science can be used for informing public debate, policy development, and adaptive management decisions, and for defining and setting the future direction and priorities of the program. The

synthesis and assessment products constitute an important new form of topic-driven integration of U.S. global change assessment efforts. These CCSP products will be U.S. Government disseminations, subject to the provisions of the Information Quality Act (Section 515 of the Treasury and General Government Appropriations Act of 2001).

SUMMARY OF SYNTHESIS AND ASSESSMENT PRODUCTS

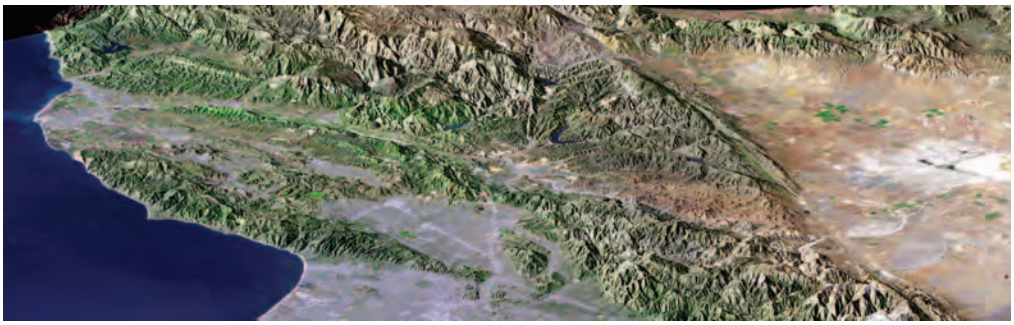
CCSP GOAL 1	Extend knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.
1.1	Temperature trends in the lower atmosphere—steps for understanding and reconciling differences.
1.2	Past climate variability and change in the Arctic and at high latitudes.
1.3	Re-analyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change.
CCSP GOAL 2	Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
2.1	Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with CCTP; review of integrated scenario development and application.
2.2	North American carbon budget and implications for the global carbon cycle.
2.3	Aerosol properties and their impacts on climate.
2.4	Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change.
CCSP GOAL 3	Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.
3.1	Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis.
3.2	Climate projections for research and assessment based on emissions scenarios developed through CCTP.
3.3	Climate extremes including documentation of current extremes.
3.4	Risks of abrupt changes in global climate.
CCSP GOAL 4	Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.
4.1	Coastal elevation and sensitivity to sea-level rise.
4.2	State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources.
4.3	Analyses of the effects of global change on agriculture, biodiversity, land, and water resources.
4.4	Preliminary review of adaptation options for climate-sensitive ecosystems and resources.
4.5	Analyses of the effects of global change on energy production and use.
4.6	Analyses of the effects of global change on human health and welfare and human systems.
4.7	Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options.
CCSP GOAL 5	Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.
5.1	Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions.
5.2	Best-practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking.
5.3	Decision-support experiments and evaluations using seasonal-to-interannual forecasts and observational data.

The synthesis and assessment products will be generated by researchers in a process that involves review by experts, public comment from stakeholders and the general public, and final approval by the departments/agencies involved in CCSP. The program has prepared and recently released guidelines for the drafting and review process that are intended to ensure consistency and transparency in preparing the products. The guidelines were made available for public comment from 29 March to 7 May 2004. They have been revised extensively in response to these comments as well as advice from the NRC provided during a meeting of the NRC's Coordinating Committee on Global Change held in Washington, DC, on 8-9 April 2004. The final guidelines, the original draft version of the guidelines, and a collation of comments submitted during the review period are all available on the CCSP web site (see <www.climatescience.gov/Library/sap/sap-guidelines.htm>).

The guidelines describe steps to be followed in each of three phases of the preparation process: developing the prospectus, drafting and revising, and final approval and publication. This methodology for product development will facilitate involvement of the research community and user groups in ensuring that the products are focused in a useful fashion and meet the highest standards of scientific excellence. The guidelines also encourage transparency by ensuring that public information about the status of the products will be provided through the Federal Register, on the CCSP web site, and through other means. If further clarification of specific issues is required, the NRC will provide advice on an as-needed basis to the lead agency responsible for the preparation of each product.

Updates on the status of some of the synthesis and assessment products to be generated in the near term are included in boxes in relevant sections of this report.

CCSP will hold a workshop in November 2005 to facilitate interaction between CCSP and the government, academic, stakeholder, and international groups participating in the CCSP process. The 3-day workshop will be held in the Washington, DC, area. The workshop announcement appears on the CCSP web site at <www.climatescience.gov/



workshop2005>. The workshop will include presentations and discussion of the initial set of synthesis and assessment products, as well as other topics related to decision support.

Commitment to "Lessons Learned" in Decision Support and Assessment

To build on the experiences of earlier assessment activities, CCSP has requested that the NRC carry out an analysis of global change assessments that have addressed topics broadly similar to those encompassed by CCSP. The analysis will examine the following aspects of global change assessments:

- Establishing clear rationales and appropriate institutional structures
- Designing and scheduling assessment activities
- Involving the scientific community and other relevant experts in preparation and review
- Engaging potential users
- Accurately and effectively communicating scientific knowledge, uncertainty, and confidence limits
- Improving global change research, including observation, monitoring, and modeling of past and future changes
- Creating assessment products that are valued by their target audiences.

Outline of Research Element Activities

The CCSP participating agencies coordinate scientific research through a set of linked interdisciplinary research elements and cross-cutting activities that encompass a wide range of interconnected issues of climate and global change. Chapters 3-15 of the *CCSP Strategic Plan* contain more detailed discussions of the research elements as well as activities that cut across all areas of the program. This report focuses on highlights of recent research and program plans for FY 2006.

Atmospheric Composition – The composition of the global atmosphere has an influence on climate and the ozone layer, as well as their relation to air quality, all of which have implications for ecosystem vitality and human health. CCSP-supported research focuses on how human activities and natural phenomena affect atmospheric composition, and how those changes relate to societally important issues such as climate change and ozone layer depletion. Emphasis is on developing the research and observing framework that will provide timely scientific information for decisionmakers in the climate arena, both in the United States and abroad.

See CCSP Strategic Plan Chapter 3.

Climate Variability and Change (including Climate Modeling) – Scientists are increasingly recognizing that short- and long-term climate variability and climate change are intrinsically linked. CCSP-supported research has made significant advances in understanding the causes of climate variations. Substantial progress has also been made in incorporating this new knowledge into frameworks for predicting future climate variability on seasonal-to-interannual time scales and for investigating the effects of human activities on climate. A new generation of climate models incorporates improved representations of physical processes, as well as increased resolution, putting them at the forefront of international research. Despite these improvements, there are still significant uncertainties associated with certain aspects of climate models.

See CCSP Strategic Plan Chapters 4 and 10.

Global Water Cycle – The water cycle plays a critical role in the functioning of the Earth system. Inadequate understanding of the water cycle is one of the dominant causes of uncertainty in climate prediction. The water cycle integrates the complex physical, chemical, and biological processes that sustain ecosystems and influence climate and related global change. New understanding of these processes will be essential to developing options and responses to the consequences of water cycle variability and change.

See CCSP Strategic Plan Chapter 5.

Land-Use and Land-Cover Change – Land use and land cover are linked to climate and weather in complex ways. Key links include the exchange of greenhouse gases between the land surface and the atmosphere, the radiation balance of the land surface, the exchange of sensible heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere. Because of these strong links, changes in land use and land cover can be important contributors to climate change and variability.

See CCSP Strategic Plan Chapter 6.

Global Carbon Cycle – CCSP-supported research on the global carbon cycle addresses the scientific questions of how large and variable the dynamic reservoirs and fluxes of carbon within the Earth system are, and how carbon cycling might change and be managed in future years, decades, and centuries. This research will help human societies evaluate their options for managing carbon sources and sinks to achieve an appropriate balance of risk, cost, and benefit. Successful carbon management strategies will require solid scientific information about the basic processes of the carbon cycle and an understanding of its long-term interactions with other components of the Earth system.

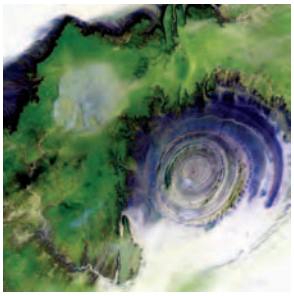
See CCSP Strategic Plan Chapter 7.

Ecosystems – Global change has the potential to affect the structure and functioning of ecosystems in complex ways. The role of CCSP-supported ecosystems research is to increase the knowledge necessary to evaluate the potential effects of global change on ecosystems in order to help society respond effectively to changes that affect the goods and services provided by ecosystems. Research focuses on changes in ecosystem structure and functioning, potential changes in the frequency and intensity of climate-related disturbances that may have significant consequences for society, and the effects of ecosystems on climate.

See CCSP Strategic Plan Chapter 8.

Decision-Support Resources Development and Related Research on Human Contributions and Responses – Decisionmakers and other interested citizens need reliable science-based information to make informed judgments regarding policy and actions to address the risks and opportunities of variability and changes in climate and related systems. A wide variety of CCSP decision-support resources and related research on human contributions and responses is targeted at that objective. The outcomes of these activities are intended to inform public discussion of climate-related issues and scientifically assess and expand options for mitigation of and adaptation to climate variability and change.

See CCSP Strategic Plan Chapters 9 and 11.



Observing and Monitoring the Climate System (including Data Management and Information) – The Interagency Working Group on Earth Observations has identified early opportunities for improved observations in disaster warning, global land cover, sea level, drought, and air quality, and has highlighted enhanced data management as an overarching need. Such cooperative efforts build upon the current GEOSS, including several new Earth-observing satellites, suborbital systems, surface networks, reference sites, and process studies now producing unprecedented high-quality data that have led to major new insights about the Earth's climate system. The United States is contributing to the development and operation of observing systems that will combine the data streams from both research and operational observing platforms to provide for a comprehensive measure of climate system variability and climate change processes.

See CCSP Strategic Plan Chapters 12 and 13.

Communication – CCSP's member agencies support a broad array of communications initiatives. CCSP has developed a strategy and implementation plan for helping to coordinate and facilitate these activities. These efforts are intended to improve public understanding of climate change research by disseminating the results of CCSP activities credibly and effectively, and by making CCSP science findings and products easily available to a diverse set of audiences.

See CCSP Strategic Plan Chapter 14.

International Research and Cooperation – CCSP, through its working groups including the Interagency Working Group on International Research and Cooperation, participates in and provides input to major international scientific and related organizations on behalf of the U.S. Government and scientific community. CCSP also provides support to maintain the central infrastructure of several international research programs and international activities that complement CCSP and U.S. Government goals in climate science.

See CCSP Strategic Plan Chapter 15.

THE U.S. CLIMATE CHANGE SCIENCE PROGRAM FOR FY 2006 CHAPTER REFERENCES

1) **NRC**, 2001: *Climate Change Science: An Analysis of Some Key Questions*. Committee on the Science of Climate Change, National Research Council, National Academy Press, Washington, DC, USA, 42 pp.
2) **NRC**, 1999: *Global Environmental Change: Research Pathways for the Next Decade*. Committee on Global Change Research, National Research Council, National Academy Press, Washington, DC, USA, 616 pp.

HIGHLIGHTS OF RECENT RESEARCH AND PLANS FOR FY 2006

1 Atmospheric Composition

Strategic Research Questions

3.1 What are the climate-relevant chemical, microphysical, and optical properties, and spatial and temporal distributions, of human-caused and naturally occurring aerosols?

3.2 What are the atmospheric sources and sinks of the greenhouse gases other than CO_2 and the implications for the Earth's energy balance?

3.3 What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?

3.4 What are the characteristics of the recovery of the stratospheric ozone layer in response to declining abundances of ozone-depleting gases and increasing abundances of greenhouse gases?

3.5 What are the couplings and feedback mechanisms among climate change, air pollution, and ozone layer depletion, and their relationship to the health of humans and ecosystems?

See Chapter 3 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Human and ecosystem well-being are related to the composition of the Earth's atmosphere. Changes in global atmospheric conditions have caused changes in climate, air quality, and the Earth's protective layer of stratospheric ozone. CCSP seeks to create a research and observation framework for atmospheric composition that provides information on the interactions among changes in the atmosphere, climate, the environment, and human health (see Figure 1) needed for sound policy decisions.

Progress in research to date has informed decisions related to laws and international treaties that protect the national and global environment. In addition, research has

revealed linkages between global change and ozone depletion, as well as local, regional, and global air quality degradation. It has become clear that these issues cannot be understood separately by scientists or policymakers. Better understanding of these connections will make possible the development and improvement of predictive models, and support more effective decisionmaking. CCSP-supported research in atmospheric composition for FY 2006 will continue to have a high-priority focus on reducing

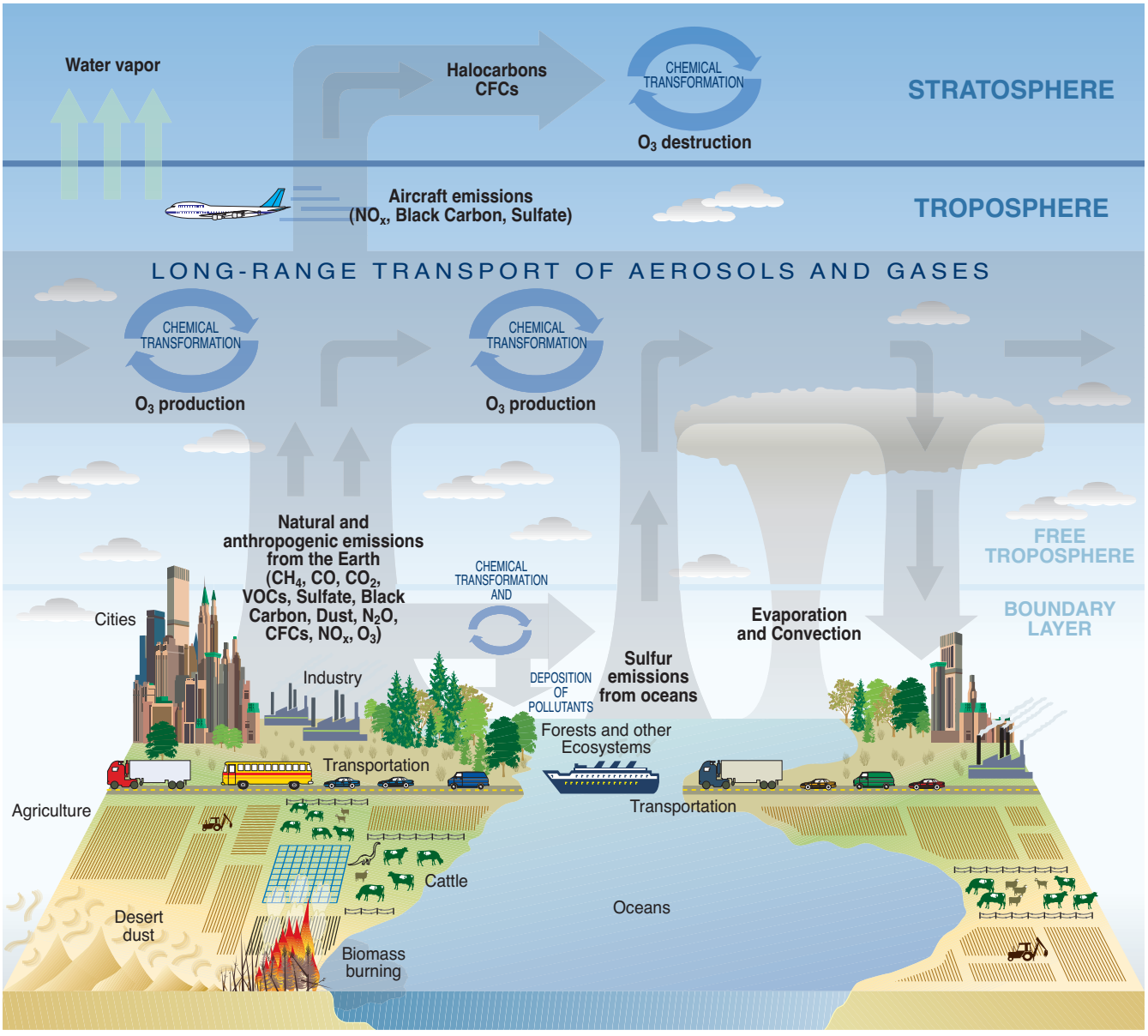


Figure 1: Chemical and Transport Processes Related to Atmospheric Composition. These processes link the atmosphere with other components of the Earth system, including the oceans, land, and terrestrial and marine plants and animals. *Credit: CCSP Strategic Plan* (illustrated by P. Rekacewicz).

scientific uncertainties associated with atmospheric aerosols (particulate matter). Aerosols are similar to greenhouse gases in that their atmospheric concentrations have increased greatly since the Industrial Revolution, and because they impose changes on the energy balance of the planet. Unlike greenhouse gases, however, different aerosols can have either a warming or a cooling influence on the climate. They also have environmental effects beyond altering climate, for example affecting regional air quality as well as human and ecosystem health in both source regions and in regions distant from the source. Observational advances have yielded important information on the geographical and vertical distribution of atmospheric aerosols and their diverse warming and cooling influences on Earth's radiation budget and their indirect effects on climate and the hydrological cycle. Nevertheless, significant further study is required to more fully quantify aerosol evolution, composition, vertical distribution, and global and regional impacts so that climate and air quality models can be more effectively evaluated and improved.

During the past 2 decades, scientists have made significant progress in understanding the causes and implications of variations in atmospheric composition. However, many questions remain. For example, halogen chemistry is known to be largely responsible for stratospheric ozone depletion, but the roles of chemistry versus dynamics remain to be fully quantified. The connection between climate change and ozone chemistry has been recognized, but uncertainties remain about the effects of climate change on the timing and extent of ozone recovery. In the troposphere, scientists have observed varying trends in ozone; however, its spatial evolution and trends remain to be quantified. Similarly, the spatial and temporal variations in oxidizing capacity – the atmosphere's ability to cleanse itself and prevent the buildup of harmful emissions – require further characterization in order to quantify the changing abundances of trace gases and aerosols. Global observations have shown the transport of tropospheric ozone over large (hemispheric) distances. However, the extent to which regional pollution can be attributed to such long-range transport remains to be quantified. In the climate area, radiatively important changes in atmospheric water vapor have been observed, but these temporal variations are not sufficiently quantified so that future changes can be projected.

Highlights of Recent Research

The following are selected highlights of recent research supported by CCSP participating agencies.

Aura Mission Successfully Launched and Operating.[7,9] The Aura satellite was launched on 15 July 2004, from Vandenberg Air Force Base, California (see <aura.gsfc.nasa.gov/test/>). Aura is already providing the first-ever daily global measurements of tropospheric ozone and many other trace gases that affect air quality. The spacecraft is delivering these results, in addition to observations of the stratosphere, with unprecedented spatial resolution. Aura's global view of Earth's atmospheric composition provides needed information for research, and for supporting environmental management and policy development related to issues of local, regional, and global air quality, climate change, and stratospheric ozone depletion and recovery. Aura carries four instruments: the Ozone Monitoring Instrument (OMI), the Microwave Limb Sounder (MLS), the High Resolution Dynamics Limb Sounder (HIRDLS), and the Tropospheric Emission Spectrometer (TES). OMI was built by The Netherlands and Finland in collaboration with NASA. HIRDLS was built by the United Kingdom and the United States.

Aura will help scientists globally monitor pollution production and transport from city-to-city, region-to-region, and continent-to continent, on a day-by-day basis, for the first time. Aura's view from space enables us to understand the long-range pathways of pollutants, and early research results using MLS measurements of carbon monoxide

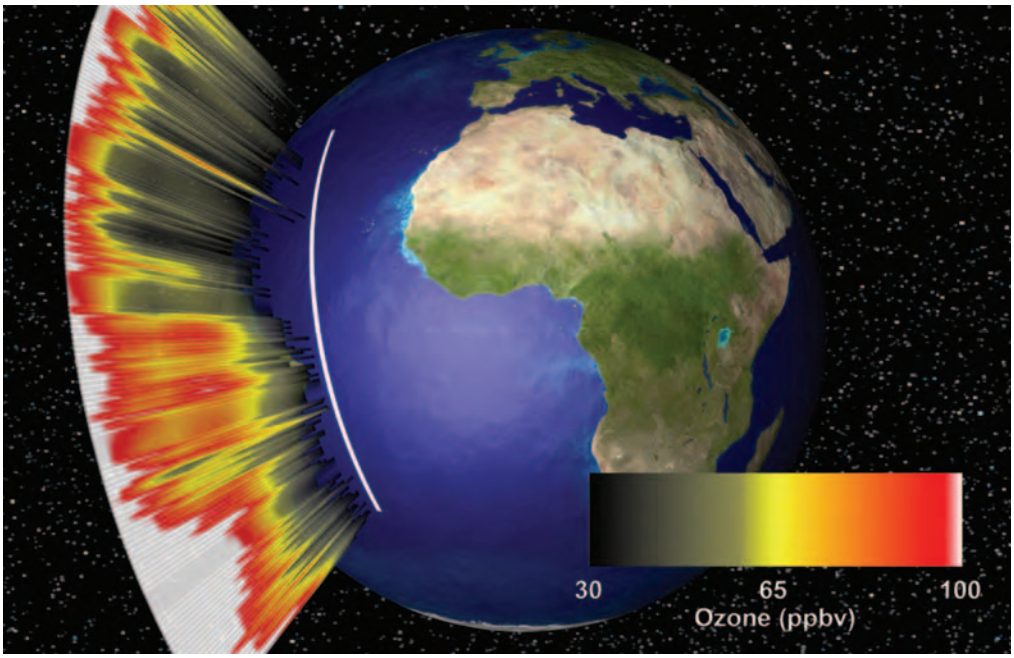
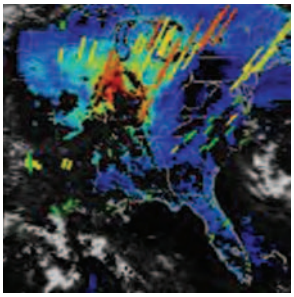


Figure 2: Aura TES Transect of Atmospheric Pollutants. The Tropospheric Emission Spectrometer (TES) on NASA's EOS Aura satellite is providing new observations of the vertical distribution of pollutants, including ozone, in the lowest part of the atmosphere. In this vertical slice taken in early September 2004 over the Atlantic, plumes of ozone that formed downwind of forest fires burning in both South America and Africa can be seen south of the equator from just above the surface to ~18 km. New measurements of pollutants and greenhouse gases such as ozone in the troposphere will allow scientists to estimate the impact of regional pollution events on global air quality and climate. *Credit: Jet Propulsion Laboratory.*

have begun to quantify the role of strong convective weather systems and long-range transport of pollution. Aura measurements also offer new insights into the processes that control the distribution of the trace gases important to climate change, and how climate changes influence the recovery of the protective stratospheric ozone layer. Analyses using measurements by the MLS instrument on Aura gave researchers the needed data to diagnose with unprecedented detail and spatial coverage polar ozone loss for the 2004 Antarctic ozone hole.

Aura instruments measure five of the six "criteria pollutants" identified by EPA. The complexity of pollution transport makes it difficult to quantify the extent to which human activities affect local air quality. In addition, the presence of the stratospheric ozone layer between the satellite and the troposphere makes "seeing" tropospheric ozone very difficult. Aura's TES uses new technology to see through the stratospheric ozone layer to measure tropospheric ozone (see Figure 2).

Aura enables new insights into the physical and chemical processes that influence the stratospheric ozone layer and climate. It is producing the most complete suite of chemical measurements ever available to understand the ozone layer and its recovery. These include the first measurements of chemically reactive hydrogen-containing species involved in ozone destruction, and the first simultaneous measurements of key forms of chlorine and bromine, which are also important for ozone destruction.



Smoke Inhibition of Cloud Formation.[6] Urban air pollution and smoke from fires can have important effects on the climate system. The net effect of aerosols on the atmospheric radiation budget and climate is a key uncertainty in attempts to model and project climate change. Aerosols can counteract regional greenhouse warming by reflecting solar radiation to space or by enhancing cloud reflectance and lifetime. However, some aerosols can add to the warming by absorbing sunlight, which also may have the effect of slowing down the hydrological cycle and reducing cloud cover.

While most greenhouse gases have long lifetimes and a homogeneous distribution in the global atmosphere, aerosols, due to their short lifetimes, have a heterogeneous spatial and temporal distribution. Thus, daily satellite observations and continuous *in situ* measurements are needed to observe the emission and transport of dense aerosol plumes downwind of populated and polluted regions and regions with vegetation fires.

Remote-sensing observations are providing the first measurements of the effect of aerosols, including sunlight-absorbing black carbon, or soot, on inhibition of cloud formation (see Figure 3). Observations by the Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Aqua satellite over the Amazon region during the biomass burning season in 2003 showed that scattered cumulus cloud cover was reduced from 40% in clean conditions down to 0% in heavy smoke

Figure 3: Reduction in Amazon Cloud Cover due to Smoke. Aerosols can have both a warming and cooling influence on global climate through a variety of diverse regional effects. This figure shows the reduction of cloudiness in a geographical region due to smoke aerosols from biomass burning. The reduction in cloud cover causes the region to reflect less sunlight, thereby allowing the surface to become warmer by the increased absorption of direct sunlight. The two satellite images of regions of the Amazon show marked difference in cloud cover due to the presence of smoke from biomass burning. The panel to the left without smoke aerosols has 40% cloud cover while the panel to the right with smoke is virtually cloud free. The partially cloud-covered region reflects an average of 36 Wm^{-2} of the incident sunlight and the cloud-free area reflects a smaller 28 Wm^{-2}. The fraction of the sunlight that is not reflected is absorbed by the atmosphere and surface. These satellite images were acquired by the MODIS instrument aboard the Aqua satellite on 3 August 2003.
Credit: R. Simmon, J. Allen, and Y. Kaufman, NASA/Goddard Space Flight Center.

conditions. The reduction of clouds due to smoke aerosols leads to less sunlight being reflected and more sunlight being absorbed by the Earth, resulting in warming. This effect may be offsetting some of the cooling attributed to sulfate aerosols.

Multi-Platform Studies of Aerosol Properties and Radiative Effects.[5]
On five occasions spanning the Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia) field campaign in spring 2001, the Multiangle Imaging Spectroradiometer (MISR) instrument on the NASA Terra satellite took data coincident with high-quality observations by instruments on two or more surface and airborne platforms. The cases capture a range of clean, polluted, and dusty aerosol conditions. A wealth of data was collected through the joint support of NSF, NASA, NOAA, and the Office of Naval Research (ONR). Scientists synthesized the data from over 40 field instruments and satellite observations into layer-by-layer environmental snapshots

that summarize what is known about the atmospheric and surface states at key locations during each event. Aerosols within a few kilometers of the surface were composed primarily of Asian dust with mixtures of pollution added from Asian and non-Asian sources. Medium- and coarse-mode particle size distributions varied little among the events; however, the column aerosol optical depth varied considerably depending on the near-surface amounts of absorbing aerosols. The consistency of component particle microphysical properties among the five events, even in this relatively complex aerosol environment, suggests that global, satellite-derived maps of aerosol optical depth and aerosol mixture (air-mass type) extent, combined with targeted *in situ* component microphysical property measurements, can provide a detailed global picture of aerosol properties and distributions, enabling studies of aerosol impacts on climate.

Intercontinental Tracking of Pollution and Aerosols. An expanse from the western United States to the European continent was the setting in summer 2004 for more than 200 scientists who participated in the largest climate and air quality study to date, the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT; see <www.al.noaa.gov/ICARTT>). The research was aimed at developing a better understanding of the factors that are involved in the intercontinental transport of pollution and the radiation balance in North America and the North Atlantic. Several U.S. agencies (with scientists in NOAA and NASA as co-leads), academic institutions, and international partners from five other countries used satellite, aircraft, shipboard, and land-based observations to obtain unprecedented information about the composition and transformation of air masses as they crossed the United States, traversed the Atlantic Ocean, and arrived in western Europe (see

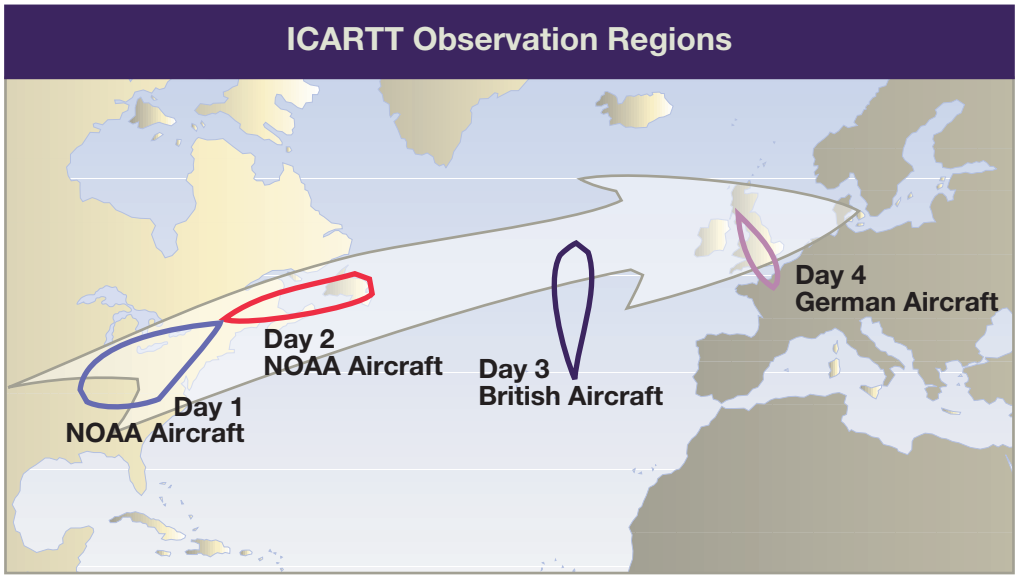
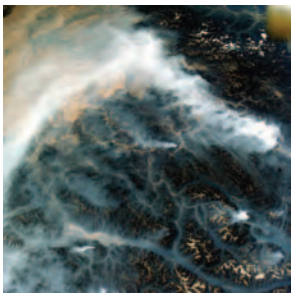


Figure 4:
ICARTT Observation Regions. Observation regions used to study intercontinental transport and transformation of gases and aerosol particles during the Summer 2004 ICARTT experiment.
Credit: O. Cooper, NOAA/ Aeronomy Laboratory.

Figure 4). Natural and anthropogenic emissions react in the atmosphere to produce gases and aerosol particles that affect climate. Tracking the sources, atmospheric transformations, and intercontinental transport of these chemical species by ICARTT is advancing U.S. and international climate research.

Nighttime Chemistry More of a Factor than Previously Recognized.[2] A new technique has enabled measurement of previously hard-to-measure trace gases in the atmosphere. The observations have opened a new frontier area in studying the atmospheric chemistry that occurs at night. The approach uses an advanced spectroscopy technique to measure trace gases in the reactive nitrogen family, some of which occur primarily at night. The gases play important roles in the chemistry that produces ozone, a greenhouse gas and pollutant that has both climate and air quality implications. In atmospheric measurements off the coast of New England, researchers found that the nighttime chemistry involving nitrogen-containing trace gases can effectively remove these gases from the atmosphere, thus "short circuit" the chemistry that would have produced ozone the next day. Related work in 2004 was aimed at developing an aircraft-ready version of the instrument and applying it in the extensive ICARTT summer climate research field campaign.

Identifying which Atmospheric Aerosol Particles are Effective "Seeds" for Cloud Formation.[3] Among the least-understood but potentially important processes in atmospheric composition science is the relationship between small aerosol particles and ice-cloud formation. The process has important implications for the radiation balance of the atmosphere. Researchers have developed a novel technique to determine the chemical composition of those aerosols capable of forming atmospheric ice clouds, commonly termed "ice nuclei," both on a particle-by-particle basis and in real time. This technique was used in 2003 and 2004 field experiments to address the need for additional and more quantitative information on the chemical composition of atmospheric ice nuclei. Among the important results was the finding that the most efficient ice nuclei are not ubiquitous sulfate aerosols, but are instead rare mineral or fly-ash particles, some of anthropogenic origin. Aerosols rich in organic material were shown to be inefficient ice nuclei. These results have contributed to our understanding of the interaction of aerosol particles with clouds and will provide valuable information for global climate models.



Studies of Transcontinental Aerosol Plumes.[1,8] Transport and transformation processes in aerosol plumes were studied in field experiments off the east coasts of Asia (2001) and North America (2002), with the aim of evaluating and refining models of chemical transport and radiative transfer. This research has shown that dust transported out of Asia over the Pacific Ocean includes not only dust, but also anthropogenic gases and particles adsorbed/reacted onto the dust. The transport of dust-pollution plumes out of Asia and across the Pacific has important implications for air quality. In addition, recent satellite data suggest that these pollution plumes are having a regional effect on the Earth's reflectivity. Results from studies in eastern North America show that plumes originating in the United States can be as intense as those downwind of India and northern Asia. The direct radiative effect of the aerosols in these plumes is thus an important factor in climate. Forthcoming data analyses will allow researchers to quantify the radiative forcing due to aerosols and to apportion this forcing based on aerosol composition and, by inference, aerosol source. The information will provide the scientific basis for informing the development of effective strategies to reduce emissions and mitigate climate impacts.

Determining Aerosol Properties from Ground-Based Measurements. Since 1979, satellite retrievals have provided excellent spatial coverage of atmospheric column ozone, certain characteristics of aerosols, and ultraviolet (UV) radiation. Satellite data from Total Ozone Monitoring Spectrometer (TOMS) instruments (<toms.gsfc.nasa.gov>) have been essential for deriving global trends in UV radiation levels and resolving critical questions about the impacts of increased UV radiation due to stratospheric ozone depletion and changes in aerosols and clouds. Continuation and improvement of the TOMS UV data record is a goal of the new Ozone Monitoring Instrument launched on the Earth Observing System (EOS) Aura satellite in 2004.

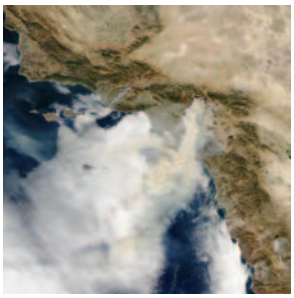
Currently, ground-based retrievals provide accurate measures of ozone needed for the validation of satellite data, as well as finer temporal resolution of these quantities necessary to determine diurnal variations and understand the observed long-term trends. An excellent example of ground-based support has been provided by the nine years of radiometer data from the CCSP-sponsored UV-B Monitoring and Research Program's (UVMRP) observational network, which has been used to assess the geographic distribution, trends, and year-to-year variability of UV-B radiation in the United States (<uvb.nrel.colostate.edu/UVB/home_page.html>).

Since 2002, CCSP's TOMS, UVMRP, and Aerosol Robotic Network (AERONET) programs have shared equipment, personnel, and analysis tools among member agencies such as USDA, NASA, and NOAA to quantify aerosol absorption using ground-based radiation measurements. Recently, UVMRP data have been used to extend measurements of aerosol properties into UV wavelengths when combined with data obtained from AERONET sun photometers (<aeronet.gsfc.nasa.gov/>).

The new analysis techniques applied to the ground-based radiation measurements provide aerosol scattering and absorption characteristics essential for determining the amount of UV radiation reaching the Earth's surface and for understanding the potential implications for climate change. Determining the spatial and temporal distribution of aerosol properties is critical for projecting climate change, understanding tropospheric chemistry, and making accurate satellite measurements of UV radiation, ozone, and aerosols.

Emissions of Ozone-Depleting Substances in Russia.[4] The emissions of six ozone-depleting substances (ODS) were estimated from measurements taken by scientists in a 17,000-km journey along the Russian trans-Siberian railway. The measurements are of global interest because Russian sources of ODS are thought to be a significant fraction of the total ODS production worldwide, and because estimates of global emissions are not in good agreement with observed atmospheric abundances over the last ~10 years. The research, based on a 2001 study, has thus far indicated that the modern emissions of ODS in Russia are too small to cause the large, contemporary shortfalls in global emission estimates. A follow-on study in spring 2004 was undertaken to examine the expected reduction of ODS concentrations since the earlier 2001 study. Preliminary results show that the abundances are indeed smaller, suggesting that the international ozone layer protection agreements of the Montreal Protocol are having their intended effect.

Highlights of Plans for FY 2006



CCSP will continue to gather and analyze information through measurement, modeling, and assessment studies to enhance understanding of atmospheric composition and of the processes affecting atmospheric chemistry. Key research plans for FY 2006 follow.

Improve Estimates of Aerosol Direct Radiative Forcing via Satellite Data Analysis. Much progress has been made in using global observations from space to assess aerosol radiative forcing, leading to the efforts planned for FY 2006. One major success is the similarity of several independent estimates of top-of-atmosphere aerosol direct radiative forcing over the ocean using satellite measurements of reflected sunlight. This success is traced to improved remote-sensing instrument calibration, spatial resolution, aerosol optical thickness evaluations, and improved algorithms for data retrieval in partially cloudy scenes.

Bottom-of-atmosphere aerosol radiative forcing is more uncertain, in part due to poorly constrained measurements of aerosol absorption and vertical distribution. Satellite observations are not able to differentiate aerosols due to anthropogenic

sources from natural aerosols. However, satellite-retrieved measurements of aerosol optical thickness, using several methods, are generally greater than model predictions, suggesting that these measurements have information to contribute to model improvement.

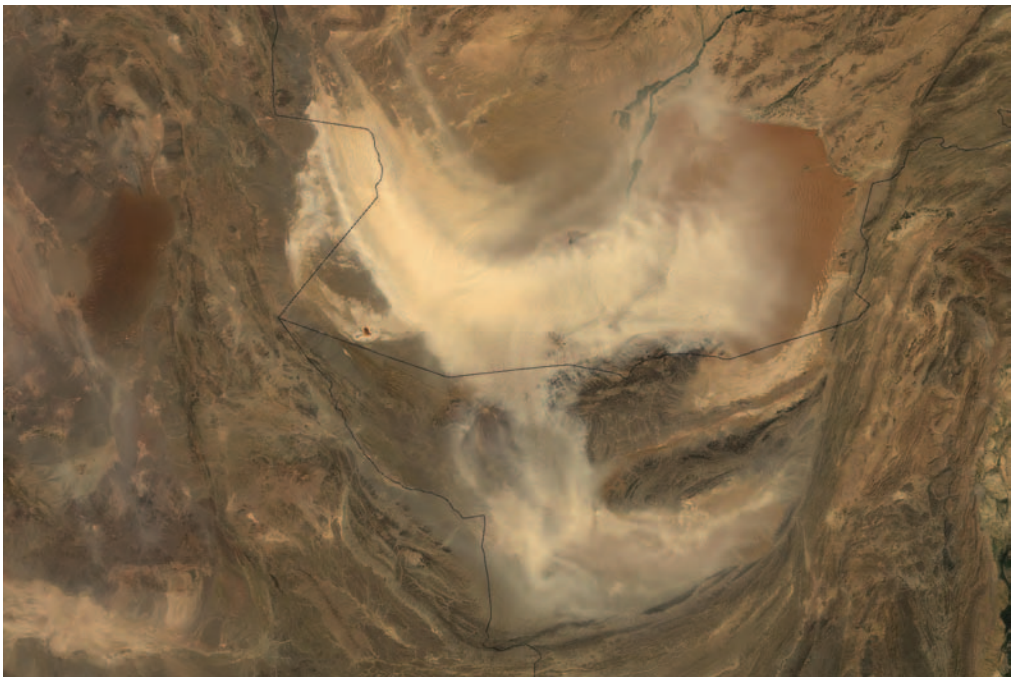
The lidar instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite, scheduled for launch in fall 2005, promises to revolutionize knowledge of aerosol vertical distribution. Efforts are being made to develop methods of integrating global satellite observations with *in situ* and surface data to fill in major gaps in observations of aerosol particle properties such as single-scattering albedo, and to help separate anthropogenic from natural components. Also, further advances in the near term are expected from multi-angle, UV, and polarization-based techniques for deriving aerosol optical thickness over land.

These activities will address Question 3.1 of the CCSP Strategic Plan.

Intercontinental Chemical Transport Experiment – North America (INTEX-NA). The INTEX-NA is an integrated series of atmospheric measurements in support of achieving the Aura science goals and validation needs through field activities to be performed over and around North America. It seeks to understand the transport and transformation of trace gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Especially important to the success of INTEX-NA are carefully conducted coincident validation and science activities associated with ongoing satellite measurement programs, such as Terra, Aura, and Envisat. Synthesis of the ensemble of observations from surface, airborne, and space platforms, with the help of a hierarchy of models, is a necessary and important step toward achieving science objectives (see <cloud1.arc.nasa.gov/intex-na/>).

These activities will address Questions 3.1 and 3.2 of the CCSP Strategic Plan.

Development of an Instrument Package for an Airborne Aerosol Observatory. To date, observations of *in situ* aerosol properties have been primarily limited to intensive field campaigns, which provide a "snapshot" in time and space. A new instrumentation package for a light airplane will be completed and fielded; this deployment will permit more extensive *in situ* observations of the vertical and horizontal distributions of aerosol chemical, microphysical, and radiative properties over clean and polluted regions of the United States. The new approach will yield aerosol properties at differing locations and times, thus leading to a better characterization of aerosol

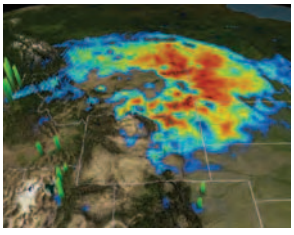


radiative properties above the surface, where few systematic measurements have been taken. They will also help validate satellite observations.

These activities will address Question 3.1 of the CCSP Strategic Plan.

Field and Laboratory Studies of Factors that Influence the Radiative Effect of Aerosols. The optical properties of aerosols are crucial parameters for calculating their radiative forcing. Laboratory studies will quantify how relative humidity affects the optical properties of aerosols of different composition. In conjunction with the laboratory studies, field measurements will examine water uptake by real atmospheric aerosols. The combination of these two measurements will better quantify how aerosols grow and how their radiative properties change under differing atmospheric relative humidity conditions. Incorporation of these real-world data in radiative transfer models, which calculate the radiative forcing of the climate system by aerosols, will reduce the uncertainty in the radiative forcing by aerosols.

These activities will address Question 3.1 of the CCSP Strategic Plan.



Potential Consequences of Climate Variability and Change for U.S. Air Quality. Researchers are conducting scenario-based analyses of the potential consequences of global change on regional U.S. air quality, focusing on fine particles and ozone. The climate, emissions, and underlying socioeconomic-based scenarios are intended to provide plausible projections of future conditions, rather than predictions of what actually will happen. Research activities focus on developing regional-scale

inputs for air quality simulations using the Community Multiscale Air Quality modeling system. The potential impacts of increases in transported pollutants due to increases in global industrialization, population, and economic activity are also being analyzed. Research from FY 2004 onward is building toward a 2007 completion of an analysis of potential changes in U.S. air quality due to climate variability and change, including direct meteorological impacts on atmospheric chemistry and transport and the effect of temperature changes on emissions of air pollutants. Further research will result in a 2010 completion of an analysis that incorporates projected emission impacts from technology, land-use, and demographic changes to construct plausible scenarios of U.S. air quality for up to 50 years into the future.

These activities will address Question 3.3 of the CCSP Strategic Plan.

Mexico City Campaign in Spring 2006. Megacities are significant sources of aerosols influencing regional and global scale climate parameters. The Mexico City Metropolitan Area (MCMA), with 18 million people, is the world's second largest megacity after Tokyo. The recent MCMA-2003 field measurement campaign, which was part of the Integrated Program on Urban, Regional, and Global Air Pollution (see <www-eaps.mit.edu/megacities>), was designed to improve knowledge of the chemistry, dispersion, and transport processes of pollutants emitted to the MCMA atmosphere. In addition to being an example of a megacity that exports aerosols to the global environment, the Mexico City area provides an opportunity to study aspects of aerosol life cycles in a unique environment characterized by very high concentrations of soot, and secondary aerosols and precursors, that can be transported from the megacity into the surrounding region, thereby affecting regional radiative balance. DOE plans to conduct a 4-week field campaign during March 2006, using a G-1 aircraft and two instrumented surface sites. The planned study will examine and characterize changes in aerosol composition, size distribution, light scattering coefficient, absorption coefficient, optical depth, soot specific absorption, and radiative fluxes at the surface in the urban plume. The timing of the field experiment will allow close collaboration between the DOE Megacity Aerosol Experiment in Mexico City (MAX-Mex; see <www.asp.bnl.gov/MAX-Mex.html>), the NSF Megacity Impact on Regional and Global Environments (MIRAGE; see <www.ucar.edu/communications/quarterly/spring99/MIRAGE.html>) experiment, and the second phase of INTEX-NA (see <cloud1.arc.nasa.gov/intex-na>). The collaboration between the Mexican-, DOE-, NSF-, and NASA-supported scientists is part of a larger effort to understand the air pollution impacts of megacities, and is referred to as the Megacity Initiative: Local and Global Research Observations.

These activities will address Question 3.3 of the CCSP Strategic Plan.

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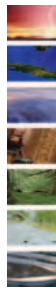
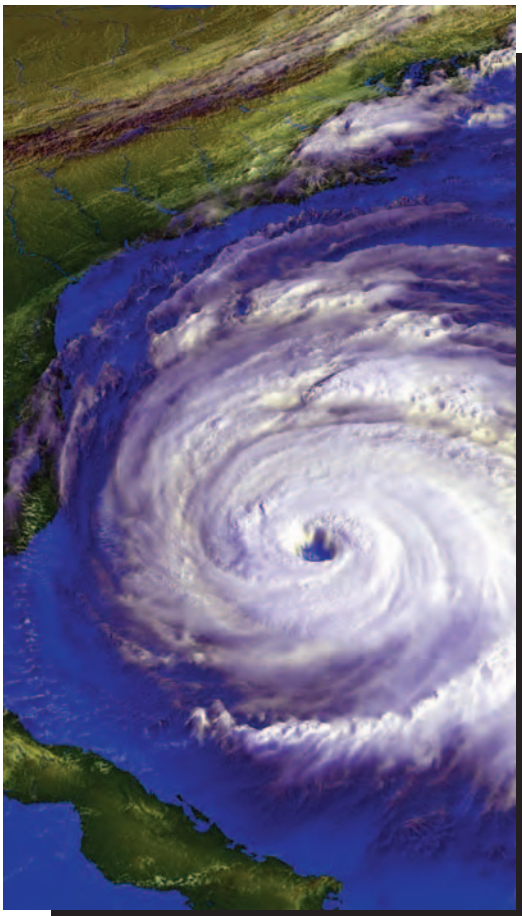




2 Climate Variability and Change

Strategic Research Questions

4.1 To what extent can uncertainties in model projections due to climate system feedbacks be reduced?

4.2 How can predictions of climate variability and projections of climate change be improved, and what are the limits of their predictability?

4.3 What is the likelihood of abrupt changes in the climate system such as the collapse of the ocean thermohaline circulation, inception of a decades-long mega-drought, or rapid melting of the major ice sheets?

4.4 How are extreme events, such as droughts, floods, wildfires, heat waves, and hurricanes, related to climate variability and change?

4.5 How can information on climate variability and change be most efficiently developed, integrated with non-climatic knowledge, and communicated in order to best serve societal needs?

See Chapter 4 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

CCSP-supported research has made significant advances in understanding the causes of climate variations. Substantial progress has also been made in incorporating this new knowledge into frameworks for predicting future climate variability on seasonal-to-interannual time scales and for projecting the potential climatic consequences of human activities.

Scientists are increasingly aware that climate fluctuations occurring at a variety of time scales are intrinsically linked. For example, future variability of El Niño and its associated global climatic impacts are likely to depend partly on how average conditions of the ocean-atmosphere system change with time. A coordinated research strategy is essential to address scientific questions associated with both short- and long-term climate variations. The climate variability and change (CVC) research component of

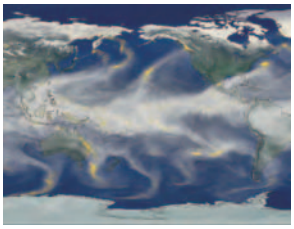
the *CCSP Strategic Plan* provides this strategy. It describes an ambitious, coordinated set of activities that builds on recent advances and is framed by two broad and important questions:

- How are climate variables that are important to human and natural systems affected by changes in the Earth system resulting from natural processes and human activities?
- How can emerging scientific findings on climate variability and change be further developed and communicated in order to better serve societal needs?

Current CVC research is addressing the five strategic research questions listed at the beginning of this chapter, which reflect the research approaches, milestones, products, and payoffs described in the *CCSP Strategic Plan*.

Making progress toward these objectives requires close cooperation among a variety of disciplines. In some cases, virtually all of the scientific elements encompassed by the CCSP agencies must come together to jointly address these challenges. The research highlights presented here provide a sampling of the breadth encompassed by the CVC component of CCSP over the past year.

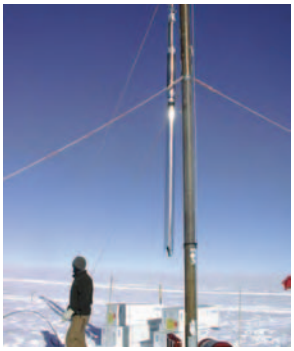
Highlights of Recent Research



Selected highlights of recent CVC research supported by CCSP participating agencies follow.

Ancient Climate of the Western United States.[1,19] Evidence indicates that the climate of northern California over the past 3,500 years has been dominated by El Niño cycles. Paleoclimatologists infer this from the width of annual growth rings of redwood trees, the contents of packrat middens (debris piles), and the chemistry of tiny planktonic foraminifera (shelled, single-cell organisms preserved as fossils in the geologic record). In addition, these scientists concluded that abundance variations in the planktonic foraminifer *Globigerinoides sacculifer* in marine cores from the western and northern Gulf of Mexico can serve as an effective proxy for the southwestern U.S. monsoon on millennial and sub-millennial time scales. The marine record confirms the presence of a severe multi-century drought centered at approximately 1,600 years before present, as well as several multi-decadal droughts that have been identified in a long tree-ring record spanning the past 2,000 years from west-central New Mexico. The marine record further suggests that the southwest monsoon circulation, thus summer rainfall, was enhanced in the middle Holocene (approximately 6,980-4,710 years before present). The marine proxy record provides the potential for constructing a highly resolved, well-dated, and continuous history of the southwest monsoon for

the entire Holocene (approximately the last 10,000 years). Records of U.S. paleoclimate such as those described above provide measures of natural variability and a context for attributing the causes of recent climate change.



Borehole Climate Reconstructions Show 500-Year Warming Trend.[18] A new analysis indicates that the average temperature of the Northern Hemisphere has increased by 1°C since A.D. 1500. This estimate is somewhat greater than Northern Hemisphere temperature reconstructions based on most inferences from tree and ice cores. Vertical temperature profiles obtained from 695 boreholes were used to make this estimate. Boreholes can be used to infer past temperatures because temperature changes at the surface affect the subsurface temperature. These subsurface changes slowly propagate downward, so that temperatures farther underground correspond to temperatures farther back in time.

***North American Drought Atlas* Indicates Increased Dryness during the Medieval Warm Period.**[6] Analyzing paleoclimate records in the western United States over the past 1,200 years, scientists found evidence that elevated aridity in the U.S. West may be a natural response to climate warming. The study revealed that a 400-year-long period of elevated aridity and epic drought occurred in what is now the western United States during the period A.D. 900-1300. This corresponds broadly to the so-called "Medieval Warm Period," a time in which various paleoclimate records indicate unusual warmth over much of the Northern Hemisphere. The study's authors used tree ring records to reconstruct evidence of drought, and also examined a number of independent drought indicators ranging from charcoal in lake sediments to sand dune activity. The team then used published climate model studies to explore mechanisms that link warming with aridity in the western United States. The authors of the new study postulate that certain mechanisms associated with warming may lead to increased prevalence of drought in the western interior region of North America. A CD-ROM summarizing the data, called the *North American Drought Atlas*, is available through the web site <www.ngdc.noaa.gov/paleo/pdsiyear.html>. It is the first of its kind, providing a history of drought on this continent. The atlas contains annual maps of reconstructed droughts over North America, including an animation of those maps showing aridity over time.

Observed Thinning of West Antarctic Glaciers.[22,23] In the wake of the Larsen B Ice Shelf disintegration in 2002 (see Figure 5), glaciers in the Antarctic Peninsula have thinned and their movement to the Weddell Sea has accelerated. According to another study conducted by U.S. and Chilean researchers, glaciers in West Antarctica are shrinking at a rate substantially greater than was observed in the 1990s. They are losing 60% more ice into the Amundsen Sea than they accumulate from inland snowfall. The

ice loss from the measured glaciers corresponds to an annual sea-level rise of 0.2 mm (0.008 in), or more than 10% of the total global increase of about 1.8 mm (0.07 in) per year. Ice shelves in the Amundsen Sea appear to be thinning, offering less resistance to their tributary glaciers. The findings suggest that ice shelf breakup may lead to an increased rate of sea-level rise.

Projected Heat Wave Intensity, Frequency, and Duration.[16] Results under a "business-as-usual" scenario using a global coupled climate model (the Parallel Climate Model, PCM) project a geographic pattern to future changes in heat waves. This model projects that areas in Europe and North America could experience more intense, more frequent, and longer lasting heat waves in the second half of the 21st century. Observations show that present-day heat waves over Europe and North

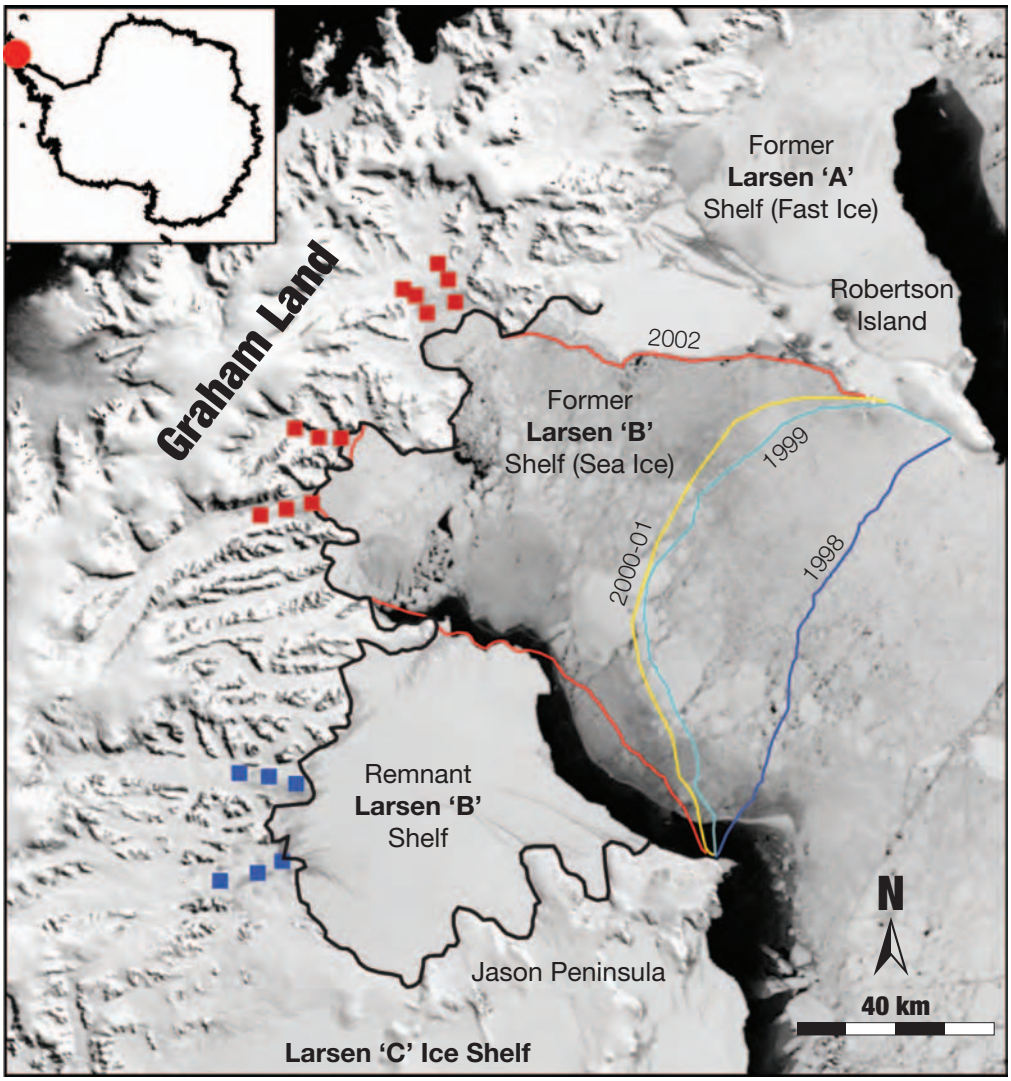


Figure 5: Retreating Margin of the Larsen B Ice Shelf. Colored lines show the retreating margin of the Larsen B ice shelf from 1998 through 2002. The red squares indicate glacier velocity measurement sites where speed increased significantly in the 12 months following the 2002 ice shelf breakup—up to a five-fold flux increase in some places. Measurements at sites indicated by the blue squares showed no large velocity changes. The 1 November 2003 base image is from MODIS Terra. *Credit: T. Scambos, NOAA/ National Snow and Ice Data Center.*

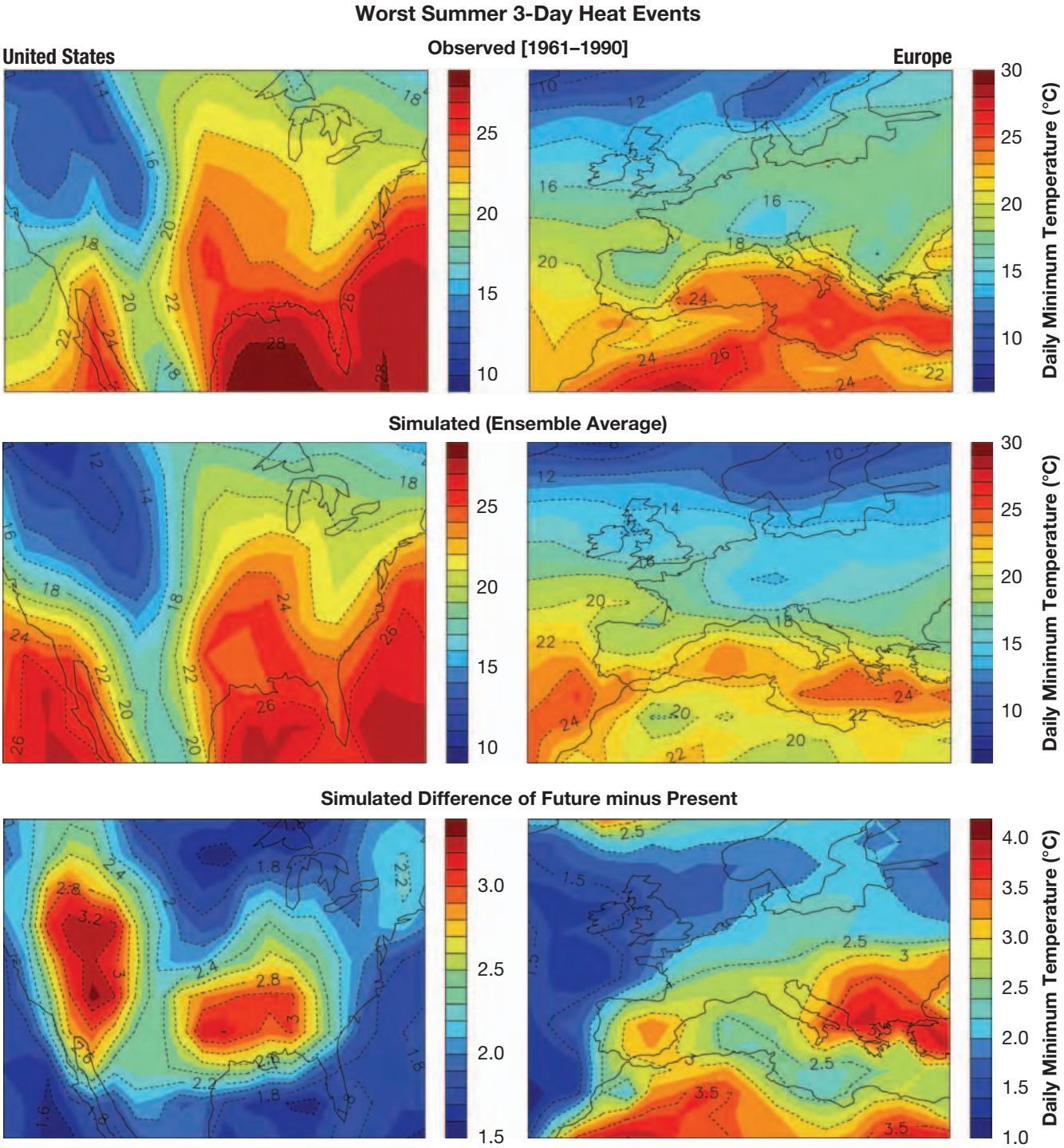
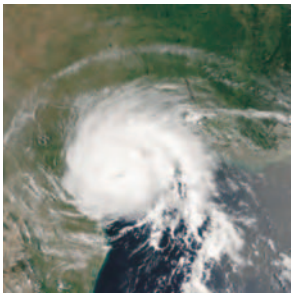


Figure 6: Worst Summer 3-Day Heat Events. The top row shows observed daily minimum temperature maps of the mean annual warmest 3-day heat waves in the United States (left) and Europe (right) for 1961 to 1990. The middle row shows the ability of the Parallel Climate Model to simulate these heat waves. The bottom row shows the increased heat wave intensities that are projected by the model for the United States and Europe in the period 2080 to 2099.
Credit: G.A. Meehl and C. Tebaldi, National Center for Atmospheric Research.

America coincide with specific atmospheric circulation patterns that are projected by the PCM to be intensified by increases in greenhouse gases (see Figure 6).



Projected Changes in Hurricane Intensity and Rainfall.[13] A recent study makes use of nine independent computer simulations of global climate change produced by different research institutions from around the world. In all, 1,300 simulated "hurricanes" were generated using a higher resolution version of a current operational hurricane model forced by 80-year future "business-as-usual" climate model projections. Results of this study indicate a modeled link between surface oceanic warming and a change in the intensity of simulated tropical storms. By 2080, the model-projected changes resulting from approximately doubled carbon dioxide concentrations could cause an average increase of approximately one-half a category in intensity (see Figure 7) and an 18% increase in rainfall within 60 miles of the storm's center. Better understanding is needed of how natural climate variations influence the frequency, severity, and favored paths of hurricanes, how the climate system responds to increased greenhouse gas concentrations, and how key physical processes (e.g.,

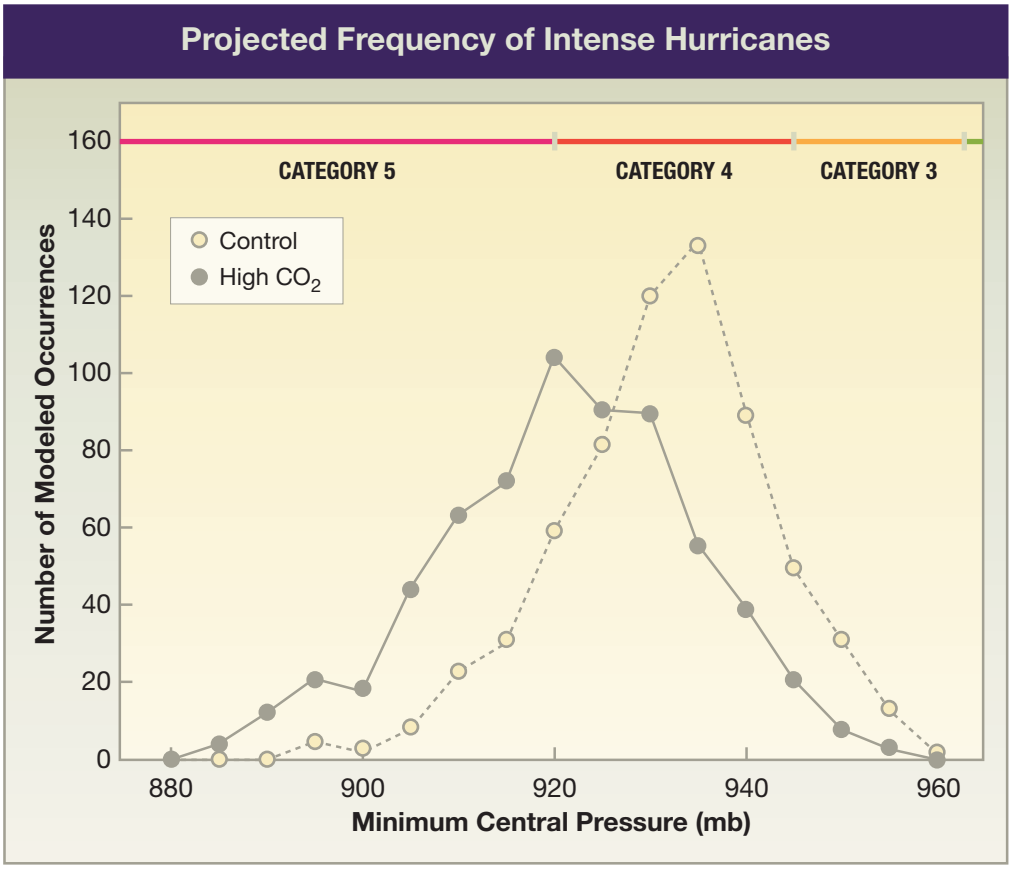
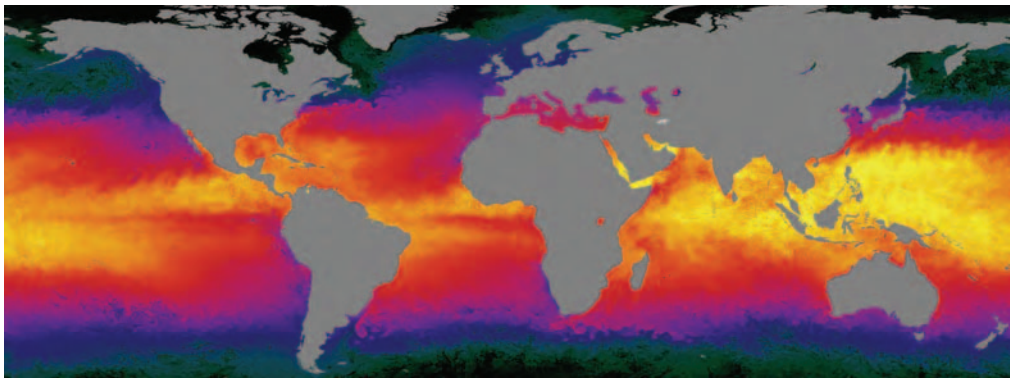


Figure 7: Projected Frequency of Intense Hurricanes. Via a high-resolution version of the GFDL hurricane prediction system, the model-projected increase in frequency of intense hurricanes can be seen by comparing the "control" simulation of a climate model run with present-day levels of greenhouse gases (yellow circles) to a simulation corresponding approximately to the year 2080 in which carbon dioxide levels were increased by 1% per year (brown circles). Category 4 hurricane wind speeds range from 131 to 155 mph and Category 5 wind speeds exceed 155 mph.
Credit: T. Knutson, NOAA/ Geophysical Fluid Dynamics Laboratory.

convection) are best represented in climate and hurricane models. It is essential that these advances be accompanied by improved understanding of the factors affecting societal vulnerability to hurricanes, including levels of coastal development, preparedness, and response systems.

Soot from Fossil Fuels Changes Snow Reflectivity.[10] Soot produced as a by-product of fossil-fuel burning can be carried for hundreds of miles before being deposited on the ground. Soot that falls on snow increases the snow's absorption of solar energy, thereby increasing its melting rate. Exposing bare ground may lead to further warming since it generally absorbs more solar energy than snow. A new study indicates that this effect may have contributed to some of the global warming of the past century, including a portion of the trend toward early springs in the Northern Hemisphere, thinning Arctic sea ice, and melting land ice.

Subpolar North Atlantic Circulation Changes during the 1990s.[8] The giant vortex of an ocean current, or gyre, in the northwestern North Atlantic appears to have slowed. Observations of sea-surface height reveal that significant changes have occurred over the past decade in the mid- to high-latitude North Atlantic Ocean. TOPEX/Poseidon altimeter data show that the average sea-surface height increased during the 1990s in this region. The same measurements were used to infer that ocean surface current velocities likely declined during the 1990s in the subpolar gyre. Combining the data from earlier satellites, researchers found that this circulation pattern may have been weakening since at least the late 1970s. Direct observations in the boundary current of the Labrador Sea support this interpretation. The direct observations also indicate that the associated deep underwater current is weakening as well. These changes are potentially significant because the Atlantic Ocean circulation patterns are responsible for redistributing a substantial portion of Earth's heat from low latitudes to high latitudes, making Europe much warmer than it would be without these currents.

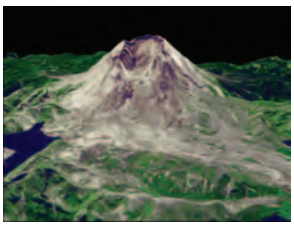


New Insights into Predictability of El Niño Events.[3] Forecasts of El Niño climate events are routinely provided and distributed, but the limits of how accurately and how far in advance El Niños can be predicted are still a subject of debate. Previous studies suggest that forecast abilities are largely limited by the effects of high-frequency atmospheric variations, or by the growth of small initial errors in model simulations. In a recent study using an advanced coupled ocean-atmosphere model, researchers made retrospective forecasts of the interannual climate fluctuations in the tropical Pacific Ocean for the period 1857 to 2003. This is several times longer than any previous experiment of this kind. The model demonstrated significant skill in predicting El Niño events back to the 19th century. Furthermore, strong El Niño events had some predictability up to 2 years in advance. The research suggested that El Niño events may be more predictable than previously thought. Additionally, the study suggests that one of the keys to better El Niño predictions is accurate initial conditions (i.e., the state of the ocean-atmosphere system as determined by observations of ocean temperatures, sea surface temperature, surface winds, etc., at the beginning of the model simulation).

Tropical Sea Surface Temperatures Affect Northern Hemisphere Winter.[11] Recent research suggests that long-term variability in tropical sea surface temperature (SST) has had an important effect on regional changes in the winter climate of the Northern Hemisphere during the last half of the 20th century. The warming of tropical Indian and western Pacific Ocean surface temperatures since 1950 has been related to unusual changes in the winter North Atlantic and European climate. The changes are characterized by a trend in indices of the North Atlantic Oscillation, the most recurrent regional pattern of atmospheric variability in the Northern Hemisphere mid-latitudes. The changes also include decadal-scale climate variability over the North Pacific Ocean and adjacent continents that affects agricultural harvests, water management, energy supply and demand, and fisheries yields. The link between northern climate variability and the tropical oceans suggests a potential basis for improving climate

predictions. This work also indicates the potential value of determining the future course of tropical SST patterns for improving projections of regional climate changes.

Feasibility of Constructing Three-Dimensional Climate Analyses Prior to 1948.[25] A recent study has shown, for the first time, that it is possible to produce a three-dimensional depiction of the atmosphere back through at least the beginning of the 20th century. A number of such three-dimensional "reanalysis" data sets have been produced by integrating past observations together within state-of-the art climate models – but never before 1948, which is when upper-air observations made by weather balloons became broadly available. Extending the three-dimensional reanalyses to earlier time periods would significantly increase their potential to support a variety of applications that to date have not been possible for the first half of the 20th century, including improving descriptions and understanding of long-term variability in mid-latitude storm systems; improving understanding of the atmospheric circulation associated with extreme events such the 1930s drought in central North America or the prolonged wet period that led to overestimates of precipitation, hence over-allocation of water resources, in the Colorado River; and creating a longer period over which to evaluate climate models driven by changes in greenhouse gases, aerosols, and solar activity. The results suggest that reanalysis is feasible extending back as far as the late 19th century and may yield useful analyses from the surface through much of the lower troposphere at daily time resolution.



Developments in Climate Modeling†

A new generation of climate models has significantly improved representations of physical processes, as well as increased resolution, putting them at the forefront of international research. New simulations of climate change during the 20th century have been completed using these models. Various high-end modeling centers sponsored by DOE, NASA, NOAA, and NSF developed and tested the new models. All show significant improvements compared to their predecessors a decade ago.

Figure 8 shows an example of output from recent simulations using four of the leading U.S. climate models, compared with satellite-based observations. Although the detailed evolution of temperature differs in models and observations, both show a common picture of gradual stratospheric cooling, which is caused by the combined effects of ozone depletion and increases in well-mixed greenhouse gases. Superimposed

† Refer to the Climate Variability and Change Chapter References box on pages 52 and 53 for citations associated with the models discussed in this subsection, specifically reference numbers 2, 4, 5, 7, 9, 12, 14, 15, 17, 20, 21, 24, and 26.

on this overall cooling are the short-term (1- to 2-year) warming signatures of the El Chichón and Pinatubo volcanic eruptions.

U.S. climate modeling capability has advanced significantly in the last 4 years. Output from the four U.S. models shown in Figure 8 is available for the CCSP synthesis and assessment products and the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report*. An extensive database, including the output from these models, is archived and made accessible to interested climate researchers through an enabling technology (Earth System Grid; see <www.earthsystemgrid.org>) and the Program for Climate Model Diagnosis and Intercomparison (PCMDI; see <www-pcmdi.llnl.gov>). It is anticipated that upcoming analyses of these climate model projections will yield fresh insights into climate variability and change. A special interagency grants program was implemented to accelerate analyses of the 20th century historical simulations. A subset of the data useful for research on the potential effects of climate change on climate-sensitive resources and systems is being made available through the IPCC Data Distribution Center (DDC; see <ipcc-ddc.cru.uea.ac.uk/>). A major effort in

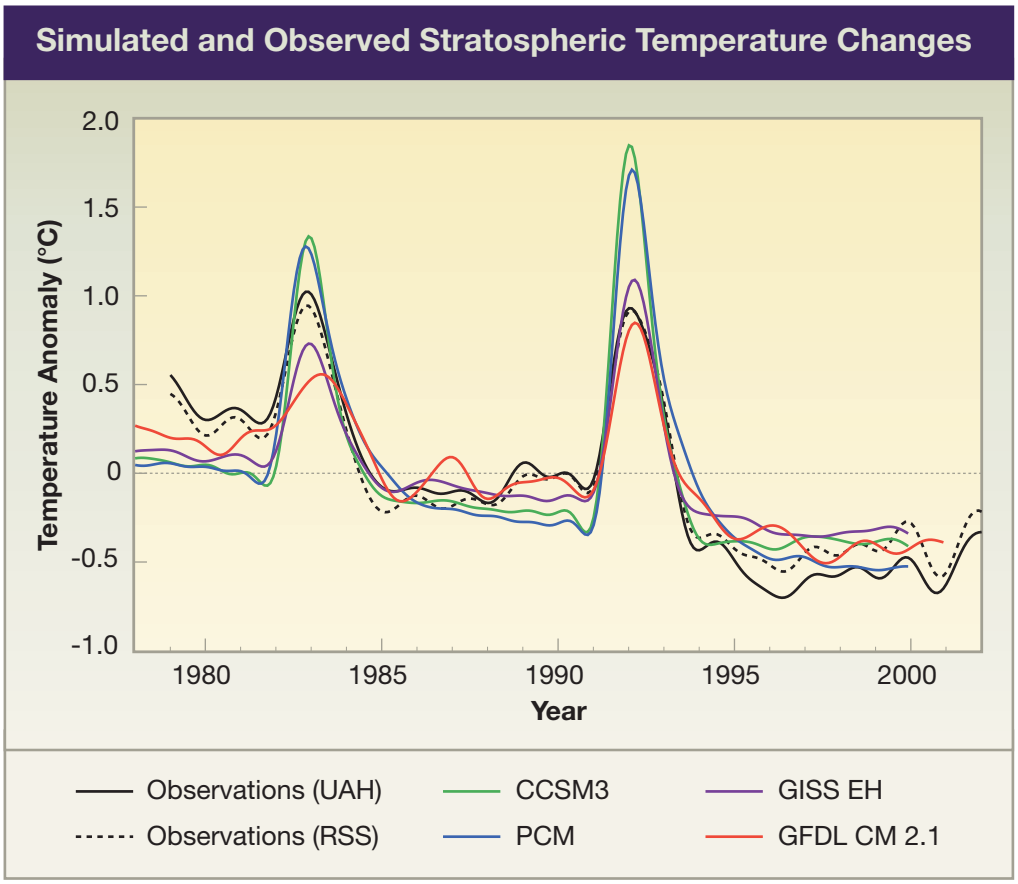
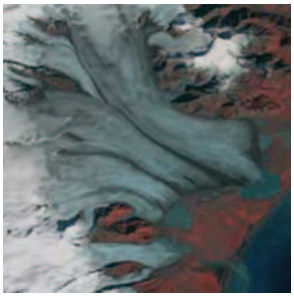


Figure 8: Simulated and Observed Stratospheric Temperature Changes. Globally averaged temperature anomalies for the lower stratosphere simulated by four global climate models using estimates of natural and anthropogenic forcings (in color) and observational values (in black) from two different satellite data sets. Model runs were conducted by the Parallel Climate Model (PCM, blue); the Community Climate System Model, version 3 (CCSM3, green); the Geophysical Fluid Dynamics Laboratory Climate Model, version 2.1 (GFDL CM 2.1, red); and the Goddard Institute for Space Studies climate model (GISS EH, purple). Observed estimates of lower stratospheric temperature changes are from channel 4 of the satellite-based Microwave Sounding Unit—produced by the University of Alabama in Huntsville (UAH, solid black) and Remote Sensing Systems in Santa Rosa (RSS, dashed black).
Source: B. Santer, Lawrence Livermore National Laboratory.

the coming years will be to assess the capabilities of these and related models for simulating regional climate change. Preliminary indications are that these models possess some skill at regional scales.

Despite the recent model improvements, there are still significant uncertainties associated with aspects of climate models. One of these is the representation of clouds, which remains one of the weakest links in modeling the physical climate system. New integrated approaches have been developed to address this challenge, taking advantage of new high-resolution satellite data, field observations, and small-scale cloud models. Important work in this area is being carried out by the Climate Variability and Predictability (CLIVAR) program's Climate Process Teams supported by CCSP. The Climate Change Prediction Program–Atmospheric Radiation Program Parameterization Testbed (CAPT; see <www-pcmdi.llnl.gov/projects/model_testbed.php>) project is also addressing the cloud modeling problem through a novel approach that includes analyzing the ability of a climate model to accurately simulate weather events, diagnose the errors, and subsequently improve the model. One example of success in this work is an improved model representation of the processes that trigger precipitation. An improved model representation of vertical cloud overlap has been incorporated in the Geophysical Fluid Dynamics Laboratory (GFDL) and Canadian general circulation models as well as the European Centre for Medium-Range Weather Forecasts numerical weather forecast model.

As noted elsewhere in this report, improvements are being made in understanding and modeling other components of the Earth system, including atmospheric chemistry, ecosystems, and carbon cycling. Efforts are underway to integrate these efforts in increasingly comprehensive Earth system models.



Highlights of Plans for FY 2006

CCSP will continue to enhance observational and modeling capabilities for improved understanding, prediction, and assessment of climate variability and change. It will do so by vigorously pursuing the goals described in the *CCSP Strategic Plan*. The CVC activities planned for FY 2006 place particular emphasis on analyzing climate feedbacks and sensitivity to natural and human-induced forcing, as well as on improving climate modeling systems. The CVC efforts will continue to place high priority on research areas that can provide an improved scientific basis for informing critical policy and resource management decisions (see, for example, the box on CCSP synthesis and assessment products focused on the physical climate system). Some of the activities that will address these goals and emphases are described in the following subsections.

CCSP SYNTHESIS AND ASSESSMENT PRODUCTS

The *CCSP Strategic Plan* identifies 21 planned synthesis and assessment products describing the current state of knowledge concerning many different aspects of climate and global change. Examples of three of these, focused on the physical climate system, are outlined below.

Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences. Independently produced data sets that describe the four-dimensional atmospheric temperature structure from the surface through the lower stratosphere indicate different temperature trends. These differences are seen in comparisons of separate *in situ* (surface and weather balloon) data sets, in comparisons of separate space-based data sets, and in comparisons of individual data sets drawn from the different observational platforms and different trend analysis teams. While previous efforts have addressed these uncertainties, the complexities of the issue, coupled with shortcomings of the available observing systems, have left a number of fundamental questions unanswered. Recent work with weather balloon and satellite data sets has provided new material for analysis and interpretation that will be included in this synthesis and assessment product, which will describe the trends and uncertainties in the lower atmospheric temperature records. The report will also present recent modeling results to assess relationships between imposed forcings (natural and human-induced) and simulated effects. The report has been reviewed by the National Research Council (NRC) and will be disseminated in FY 2006.

Past Climate Variability and Change in the Arctic and at High Latitudes. The Arctic is characterized by significant natural variability but recently has warmed more rapidly than almost any other region of the globe. The recent warming has been accompanied by a decrease in sea-ice cover and thickness and a decrease in ocean salinity. In addition, the permafrost has melted significantly in recent years. The impacts on humans and ecosystems associated with these changes were recently reported in the *Arctic Climate Impact Assessment*. This international study was partially funded by CCSP participating agencies. The Arctic and High Latitude Synthesis and Assessment Product will focus on the state of knowledge concerning past changes in the physical climate of this region, including how the recent changes compare to the longer term record and the extent to which they are historically unique. This information is vital since high-latitude regions are projected to experience the greatest warming in the future. The prospectus is currently being developed for this report. The bulk of the work on this product will be carried out in FY 2006.

Climate Models and Their Uses and Limitations, including Sensitivities, Feedbacks, and Uncertainty Analysis. Computer simulation models of the coupled atmosphere-land-ocean-sea ice system are essential scientific tools for understanding and predicting natural and human-caused changes in the Earth's climate. The purpose of this CCSP report is to provide guidance for the appropriate application of climate models and results of climate model experiments. It will describe the strengths and limitations of climate models at different spatial and temporal scales. It will focus on natural and human-caused factors influencing climate variability and change during the period 1870 to 2000, and will characterize sources of uncertainties in comprehensive coupled climate models, as well as high-resolution models used to downscale the coupled model results to regional scales. The prospectus is currently being developed for this report. The bulk of the work on this product will be carried out in FY 2006.

Key Climate Modeling Research Plans for FY 2006

Develop and Utilize Improved Climate Models. A number of modeling-related payoffs will occur in FY 2006, building on CCSP's broad range of CVC-related research activities. Several new climate model versions will be released and several new model simulations will be performed, providing an unprecedented perspective on past and future climate change:

- NASA's Goddard Institute for Space Studies (GISS) is scheduled to release a new climate model (Model E), containing a number of improved components. It will be more modular than previous versions, allowing its components to be tested in other models. NASA will also release a new version of the GEOS atmospheric climate model (GEOS5). This next-generation climate model will be coupled with

the NOAA National Centers for Environmental Prediction (NCEP) system for assimilating meteorological observations into a standard framework. This will provide an important tool for the research community to assess the model's ability to simulate weather events. GEOS5 includes components developed jointly with the National Center for Atmospheric Research (NCAR), NCEP, and GFDL.

- Developmental and historical runs will be carried out at GFDL with an Earth system model that includes interactive chemistry, carbon, and nitrogen cycles. GFDL will produce climate simulations for research and assessment based on emission scenarios developed through the Climate Change Technology Program. Likely case studies will include exploring the range of plausible future environmental consequences of various emission rates resulting from combinations of different technologies.
- Development of the next-generation Community Climate System Model (CCSM-4) at NCAR will continue, and will include atmospheric chemistry, coupled biogeochemistry, and middle atmosphere components, as well as improved physics and dynamical components. In FY 2006, researchers involved in the CCSM activity will be undertaking research and model development in areas that are often not included in climate models – for example, stratosphere-troposphere interactions (including interactive atmospheric chemistry), biogeochemical feedbacks due to carbon, and other key components. In addition, a complete suite of CCSM and PCM ensemble simulations will be performed under various IPCC forcing scenarios.
- Ambitious new approaches are being developed that have the potential to leapfrog some of the limitations of existing climate modeling methodologies. One approach is the development of a geodesic climate model that uses a radically new grid for both the atmosphere and ocean, intended to solve many of the long-known problems with both latitude-longitude grids and spectral methods. The model also uses "floating" vertical coordinates for both the atmosphere and ocean. Another novel approach is a multi-scale modeling framework that embeds cloud-resolving models in climate models. This addresses one of the most confounding issues in simulating future climate: accurately representing cloud effects despite the coarse grids of current models.
- A Modeling, Analysis, and Prediction Modeling Environment will be implemented in FY 2006 to provide open access and collaboration among Government agencies and the research community developing Earth system models and components.

These activities will address Goals 1, 2, and 3 of the CCSP modeling strategy, Goal 2 of the CCSP decision support strategy, and Questions 3.5, 4.1.4, and 7.5 of the CCSP Strategic Plan.

Archive, Distribute, and Analyze Model Output. Multi-century climate simulations produced by high-end climate models, both nationally and internationally, will be archived and distributed by PCMDI. This program will continue to make these invaluable data sets available to the climate research community and other stakeholders

through enabling technologies such as the Earth System Grid, which addresses the formidable challenges associated with analyzing the massive amounts of data produced by global Earth system models. Through a novel combination of computer technologies, the Earth System Grid will provide a seamless and powerful environment that facilitates these analyses intended to improve understanding of models' strengths, weaknesses, and opportunities for improvement. Comparisons between the observed and simulated global and regional climates of the late 19th and 20th centuries will be completed and published in FY 2006 under the Climate Model Evaluation Project. These diagnostic analyses are the latest in an ongoing series of model performance assessments that are providing a valuable yardstick for evaluating the quality of climate projections into the 21st and 22nd centuries.

These activities will address Goals 2 and 3 of the CCSP modeling strategy, Goal 2 of the CCSP decision support strategy, and Goals 1, 2, and 4 of the CCSP data management and information strategy.

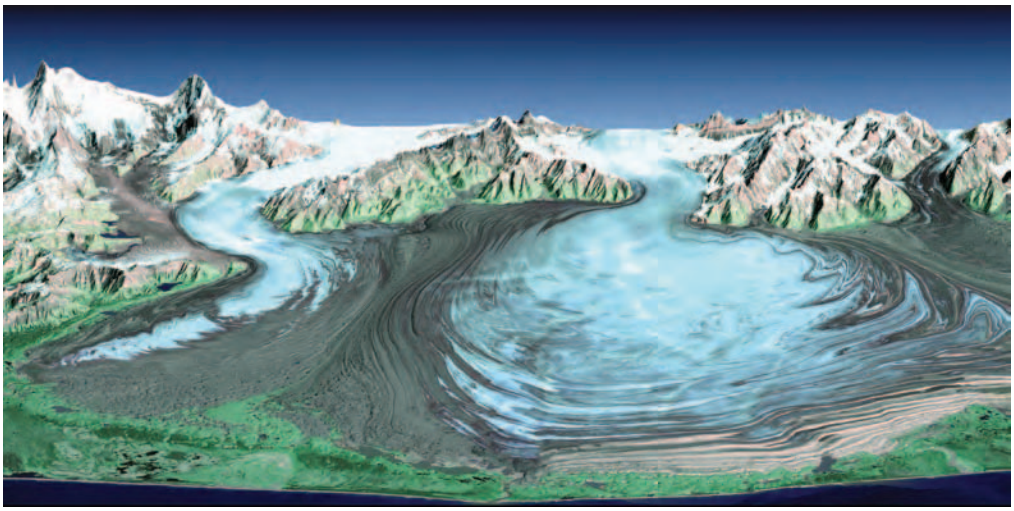
Key Observations and Process Studies Research Plans for FY 2006

Detection and Attribution of Climate Change. One of the most important questions in climate science is the extent to which humans have caused and may continue to cause climate change. Model results are sensitive to uncertainties in the "forcing factors" that lead to climate change over time. Refined estimates of forcing variables such as solar output and aerosol concentrations (both volcanic and human-induced) will be used as inputs for paleoclimate and modern model runs. The results will be evaluated in FY 2006 for the magnitude and pattern of climate response to these variables. This effort will provide the most rigorous assessment to date of the uncertainty in model-derived fingerprints of anthropogenically and naturally forced climate change. Inter-model differences will be explicitly accounted for in the detection methodologies to further understand sources of uncertainty in attribution claims.

These activities will address Goal 1 of the CCSP modeling strategy and Question 4.1.5 of the CCSP Strategic Plan.

Improve Understanding of Abrupt Climate Change. The *CCSP Strategic Plan* identifies abrupt climate change as a high-priority research topic. Ongoing research will continue to focus on the mechanisms that may give rise to abrupt climate changes, their potential predictability, and regional to global impacts. A synthesis report of modern and paleoclimate observations and modeling results from work of the Consortium on the Oceans Role in Climate – Abrupt Climate Change Studies over the past 5 years will be produced, which may be used to help inform future abrupt climate change research approaches.

These activities will address Questions 4.3.1, 4.3.3, and 4.3.5 of the CCSP Strategic Plan.



Analyze Arctic Processes. Arctic processes are expected to be sensitive to climate change and are generally expected to play an important role in modulating climate change. The Mixed-phase Arctic Cloud Experiment (M-PACE) will analyze and report results of the field experiment conducted on the North Slope of Alaska in fall 2004 to improve the scientific understanding of the dynamic processes in Arctic clouds, including cloud microphysical processes and energy transfer through clouds. In addition, a prototype Arctic observing system is being created for monitoring sea ice, ocean heat content, freshwater fluxes, and ecosystem indicators.

This activity will address Goal 1 of the CCSP modeling strategy, Goal 1 of the CCSP observing and monitoring strategy, and Questions 4.1.1, 4.1.2, and 4.3.7 of the CCSP Strategic Plan.

Great Lakes Paleoclimatology. The paleoclimatology of the Great Lakes region between 9,400 and 7,700 calendar years before present will be studied in FY 2006. Three primary issues will be examined: correlation of Great Lakes low water stands to other paleoclimatic variables; evaluation of paleoclimate variability using multi-proxy data to determine past atmospheric conditions; and reconstruction of the region's paleogeography in order to model climatic and hydrologic conditions there. This study is part of a broader effort within CCSP to develop improved quantitative paleoclimatic estimates, particularly of variability on short time scales.

This activity will address Questions 4.2.6, 4.3.2, 4.4.1, 4.4.2, and 4.4.3 of the CCSP Strategic Plan.

Develop and Test New Model Parameterizations. Climate Process and Modeling Teams are identified in the *CCSP Strategic Plan* as an important avenue for improving model representations of key climate system processes. Climate Process

and Modeling Teams are multi-agency teams of university, laboratory, and modeling center scientists. In FY 2006 they will test new model representations of clouds, the flow of water along the ocean bottom, and the mixing of water in the upper ocean by small-scale circulation features (eddies). The CAPT framework, mentioned previously, will also make significant contributions to model improvements in FY 2006 by employing a new testbed for evaluating important aspects of the GFDL AM2 atmospheric model.

These activities will address Goals 1, 2, and 3 of the CCSP modeling strategy and Questions 4.1.1, 4.1.2, 4.1.6, and 4.2.1 of the CCSP Strategic Plan.

Improve Understanding of Atlantic Climate System Processes. The United States will lead and participate in numerous studies of marine processes that must be better understood to improve predictions of climate variability. One region of particular focus for CCSP in FY 2006 is the Atlantic Ocean, where CCSP will play a prominent role in the CLIVAR Mode Water Dynamic Experiment (CLIMODE), the Tropical Atlantic Climate Experiment (TACE), and the African Monsoon Multidisciplinary Analyses (AMMA). CLIMODE will investigate how deep subtropical waters of the North Atlantic Ocean form in a region of strong air-sea heat exchange, south of the Gulf Stream. This project is a mix of modeling and *in situ* and satellite-based observations, which is expected to produce improved model representations of air-sea heat exchange. TACE will investigate a region of the Atlantic where many climate models poorly simulate sea surface temperature. Through a unique combination of observations and modeling efforts, TACE will attempt to improve understanding of the coupled atmosphere-ocean processes in this region and improve their representation in climate models. U.S. involvement in AMMA will focus on climate, weather, and related aerosol issues associated with African monsoon regions.

These activities will address Goal 1 of the CCSP modeling strategy and Questions 4.2.1, 4.2.4, and 4.2.5 of the CCSP Strategic Plan.

Analyze Warm Season Precipitation in the Southwestern United States. Research will continue on the processes that influence warm season precipitation over the southwestern United States and prospects and needs for improving summer rainfall forecasts in this region. The impacts of data obtained from the 2004 North American Monsoon Experiment on model analyses will be determined, and an assessment will be completed on the ability of global and regional models to simulate the 2004 North American summer monsoon.

This activity will address Questions 4.2.1 and 4.4.4 of the CCSP Strategic Plan.

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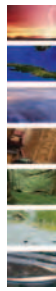


3 Global Water Cycle

Strategic Research Questions

5.1 What are the mechanisms and processes responsible for the maintenance and variability of the water cycle; are the characteristics of the cycle changing and, if so, to what extent are human activities responsible for those changes?

5.2 How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

5.3 What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

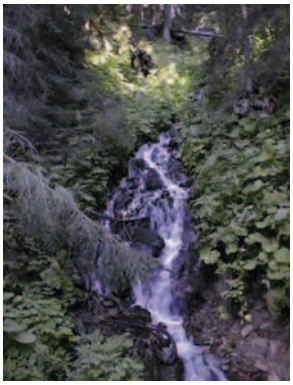
5.4 What are the consequences over a range of space and time scales of water cycle variability and change for human societies and ecosystems, and how do they interact with the Earth system to affect sediment transport and nutrient and biogeochemical cycles?

5.5 How can global water cycle information be used to inform decision processes in the context of changing water resource conditions and policies?

See Chapter 5 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The global water cycle plays a critical role in the functioning of the Earth system. Through complex interactions, the global water cycle integrates the physical, chemical, and biological processes that sustain ecosystems and influence climate and related global change. Inadequate understanding of the water cycle is one of the key sources of uncertainty in climate prediction. Clouds, precipitation, and water vapor produce feedbacks that alter surface and atmospheric heating and cooling rates, leading to adjustments in atmospheric circulation and precipitation patterns – processes current

climate models do not adequately represent. Improved understanding of these processes will be essential to developing options for responding to the consequences of water cycle variability and change. For these reasons, water cycle research is a high-priority area for near-term activities within CCSP.



Priorities in FY 2006 include the planning of integrated projects to aggressively accomplish the *CCSP Strategic Plan* goals for water cycle research. As part of this process, the CCSP participating agencies involved in the global water cycle research element are defining a program of activities that will produce the kinds of interdisciplinary breakthroughs the water cycle science community has identified as essential. These activities are organized around the need for comprehensive coincident measurements of all aspects of the water cycle, including atmospheric, surface, and subsurface observations. Observational data sets that capture key features of the water cycle at the same place and time promise to improve estimates of key fluxes and stores within the linked water and energy cycles, which are needed to balance water and energy budgets. In addition, long-term records of water cycle variables are vital for assessing changes in the Earth system. Implementation planning includes strategies for assembling long-term data sets of water cycle variables, including new tools and techniques, reanalysis of existing records, assimilation of observations and model output, and establishment of a network of observation stations with new capabilities for collecting and integrating data for interdisciplinary research. In addition to addressing CCSP goals, these ongoing and planned observations will support the objectives of the Global Earth Observing System of Systems (GEOSS).

The global water cycle research element is continuing to pursue a set of important, long-term priorities. For example, insights into the formation and behavior of clouds and precipitation, including better characterizations of the phase changes of water in clouds and the phases and onset of precipitation, are emerging from field campaigns and model studies and will be promoted in continuing activities of the global water cycle research element. Similarly, the predictability of regional precipitation will be assessed and better understood by ongoing diagnostic and modeling studies that identify the connections between regional- and global-scale phenomena, land-surface conditions (such as soil wetness), and rainstorms. Results from these studies show promise of leading to earlier (and more accurate) predictions and improved ability to assess hazards and risks of extremes such as floods and droughts, as well as more efficient water resource management. In this context, the results of advances in coupled ocean-atmosphere-land models will be important.

The ultimate goal of this water cycle research is to provide a better foundation for decisions and investments by policymakers, managers, and individuals. Achieving this

goal requires a program of activities that test predictions and data products in real decision contexts, demonstrate techniques and their effectiveness to potential users, and provide tools and strategies to transfer the science from the experimental realm to operations. Implementation of the *CCSP Strategic Plan's* global water cycle research strategy addresses these issues.

Highlights of Recent Research

Selected highlights of recent research supported by CCSP participating agencies follow. These research results address the strategic research questions on the global water cycle identified in the *CCSP Strategic Plan*.

Variations of U.S. Drought Occurrence Related to Fluctuations in Sea Surface Temperatures in the North Atlantic.[11] Researchers analyzed precipitation data to identify spatial and temporal variation of drought occurrence in the conterminous United States during the 20th century. They found that these variations were largely (74%) explained by multi-decadal fluctuations in sea surface temperatures in the North Atlantic and North Pacific Oceans and by the long-term trend in Northern Hemisphere temperatures. The results suggest that persistence of the present warm conditions in the North Atlantic into the next decade may lead to continuation of the present western drought pattern, which is similar to that of the 1950s, or to development of a drought pattern similar to that of the 1930s.

North American Climate: Water Cycle and the Pacific Decadal Oscillation.[2] Two main characteristics distinguish the Pacific Decadal Oscillation (PDO) from the El Niño Southern Oscillation (ENSO). First, 20th century PDO "events" persisted for 20 to 30 years, while typical ENSO events persisted for 6 to 18 months. Second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics – but the opposite is true for ENSO. Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO. Even in the absence of a full theoretical understanding of the PDO, information about its phase can improve season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. For the past several years, North Pacific sea surface temperature variations have not consistently correlated with either the warm or cool phases of the PDO pattern (see top panel of Figure 9). The PDO index has been highly variable. The 1900 to 2004 time series of the PDO index is shown in the bottom panel of Figure 9. Monthly updates of the PDO index are available at <jisao.washington.edu/pdo/PDO.latest>.

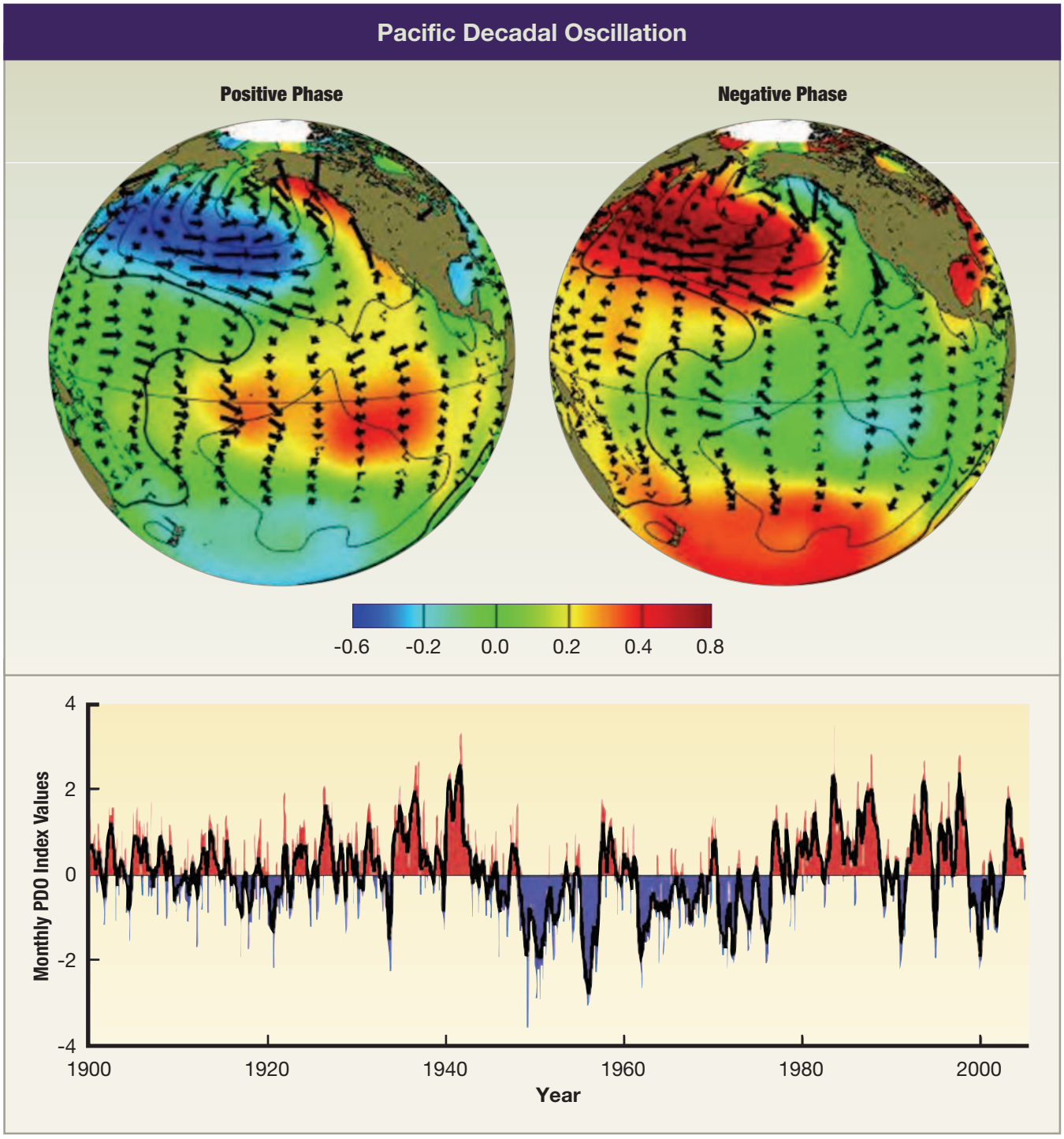


Figure 9: Pacific Decadal Oscillation.(top) Typical wintertime sea surface temperature (colors), sea level pressure (contours), and surface wind stress (arrows) anomaly patterns during positive and negative phases of the Pacific Decadal Oscillation (PDO), as derived from the TOPEX/Poseidon satellite plus other ocean/atmosphere data. Temperature anomalies (colors) are in degrees Celsius. (bottom) Monthly values for the PDO index, 1900-2004. *Credit: S. Hare and N. Mantua, University of Washington.*

Observed and Projected Changes in U.S. Snowpack and Runoff.[3,4,6,7,9,14,15] Observations from the past 5 decades indicate that the spring snowpack in the Pacific Northwest has declined significantly since the mid-20th century. At most of the mountain locations studied, declines in snow water equivalent (the depth of liquid water from the melted snow) coincide with significant increases in temperature, and have occurred despite increases in precipitation. The largest decreases have occurred at the lowest elevations, suggesting that moderate warming throughout the region may have raised the elevation of freezing level. These snowpack declines have been accompanied by an earlier annual peak in river runoff. Researchers have found that, across several hundred stream gages in mountainous western North America from New Mexico to Alaska, as well as New England, the snowmelt runoff season has come earlier in recent decades, with average timing shifts (by several measures) of 1 to 2 weeks earlier. These long-term timing shifts have been most strongly related to changes in seasonal temperatures during the snowmelt runoff season, and have not been significantly related to winter and spring precipitation. These results have significant implications for water resource managers since snowmelt provides much of the water used during summer for irrigation, energy production, municipal and industrial water supply, fish and river ecosystem protection, recreation, and other uses.

Additional studies have addressed possible implications of potential future greenhouse gas-induced climate change on the mountain snowpack and runoff in the western United States. These studies used the Intergovernmental Panel on Climate Change (IPCC) business-as-usual greenhouse gas emission scenario to drive multiple simulations of the Parallel Climate Model (PCM). In one study, annual snowpack was projected to be 20 to 70% smaller by the middle of the 21st century when the PCM output was downscaled (i.e., translated from coarse to fine resolution) with the MM5 regional climate model. Somewhat smaller snowpack reductions were found when the downscaling was performed using the Regional Spectral Model. Using the same PCM simulations, other studies suggest that reservoir levels may decline by approximately one-third in the Colorado River Basin by the end of the 21st century and that streamflow timing in most western North American streams might be roughly a full month earlier. However, there is significant uncertainty associated with downscaling climate projections to fine resolutions. Moreover, different results may be obtained if other global climate models or forcing scenarios are used. For example, the PCM projects less warming from greenhouse gas increases than most other climate models.

Projections of Global-Scale Runoff and Soil Moisture Changes.[10] Scientists have also examined the potential for significant global-scale changes in river discharges and soil wetness over the rest of the 21st century due to greenhouse warming. Their analysis of model projections, based on a typical greenhouse gas emission scenario, indicates that the discharges from Arctic rivers such as the Mackenzie may increase by up to 20% (of the pre-Industrial Period level) by the middle of the 21st century and by up to 40% or more in a few centuries. In the tropics, the discharges from the Amazon and Ganga-Brahmaputra rivers are also projected to increase substantially. However, the projected changes in runoff from other tropical and many mid-latitude rivers are smaller (on a percentage basis), with both positive and negative signs. For soil moisture, the results of this study indicate reductions during much of the year in many semi-arid regions of the world, such as southwestern North America, northeastern China, the Mediterranean coast of Europe, and the grasslands of Australia and Africa. The projected reduction is particularly large during the dry season (on a percentage basis). From middle to high latitudes of the Northern Hemisphere, this study projects soil moisture to generally decrease during the summer growing season but increase in winter.

North American Monsoon Experiment Field Campaign. Most summer precipitation around the world is driven by strong solar heating of the land surface. The consequent large summer land-ocean temperature contrasts lead to summer monsoon circulations typically characterized by a systematic reversal of wind patterns and very strong rainfall events. The North American summer monsoon is one major component of the world's monsoon systems, the others being the Asian-Australian monsoon and the African monsoon systems. These systems interact with the El Niño/La Niña cycles, among others. The North American Monsoon Experiment (NAME) field campaign was conducted in, over, and around the southwestern United States and northern Mexico during the summer of 2004 and involved internationally coordinated research (see <www.cpc.ncep.noaa.gov/products/precip/monsoon/NAME.html>). NAME aims at determining the sources and limits of predictability of summer precipitation from the monsoon over North America. The field campaign was motivated by previous and ongoing diagnostic and modeling studies, which identified processes contributing to the variability of monsoonal circulation, convection, and precipitation. The field experiment significantly enhanced the spatial and temporal resolution of observations of those processes available for the monsoon region. The results of NAME, currently being analyzed, will be used to attempt to improve warm-season weather predictions in 2006 and beyond.

Madden-Julian Oscillation and Floods.[1] Recent studies have revealed relationships between the Madden-Julian Oscillation (MJO) and precipitation that may provide an important key to prediction of flooding over southwest Asia. The MJO (also referred to as the 30-60 day or 40-50 day oscillation) is thought to be one of the main intra-seasonal fluctuations that explain weather variations in the tropics. The MJO is associated with variations in surface and upper-level wind fields, sea surface temperature, and cloudiness/rainfall. It affects the entire tropical troposphere, but is most evident in the Indian and western Pacific oceans with an active (wet) phase and an inactive (dry) phase. The MJO is strongest in the eastern Indian Ocean, when its wind anomalies extend over southwest Asia. A 22-year record of precipitation observations over southwest Asia shows that there is a 55% increase in daily precipitation when the MJO is in its active phase. The effect of the MJO is quite consistent from year to year, with more rain attributed to the MJO as it circumnavigates the globe in each of the 22 years in the record. These findings indicate that the evolutions of storms over southwest Asia and resultant precipitation could conceivably be forecast with some skill for 3-week periods.

Glacier Mass-Balance Records Show a Retreating Trend in Alaska Glaciers.[5] CCSP-supported scientists continue to monitor long-term glacier mass balance at three benchmark glaciers in Washington and Alaska, each in a different climate regime. Winter accumulation, summer ablation, and net mass balance are measured using accepted glaciological techniques. The data collected are posted on the Internet (see <ak.water.usgs.gov/glaciology>). The mass balance records extend for 50 years at South Cascade Glacier, Washington, and 38 years at Gulkana and Wolverine Glaciers, both in Alaska. These records are among the longest in North America. The data are used to understand glacier-related hydrologic processes and to improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change. Consistent with the observed warming, for the past quarter century these glaciers have experienced almost continuous negative net balances, indicative of the glacier retreat observed in the glaciated regions of the Pacific Northwest and Alaska (see Figure 10).

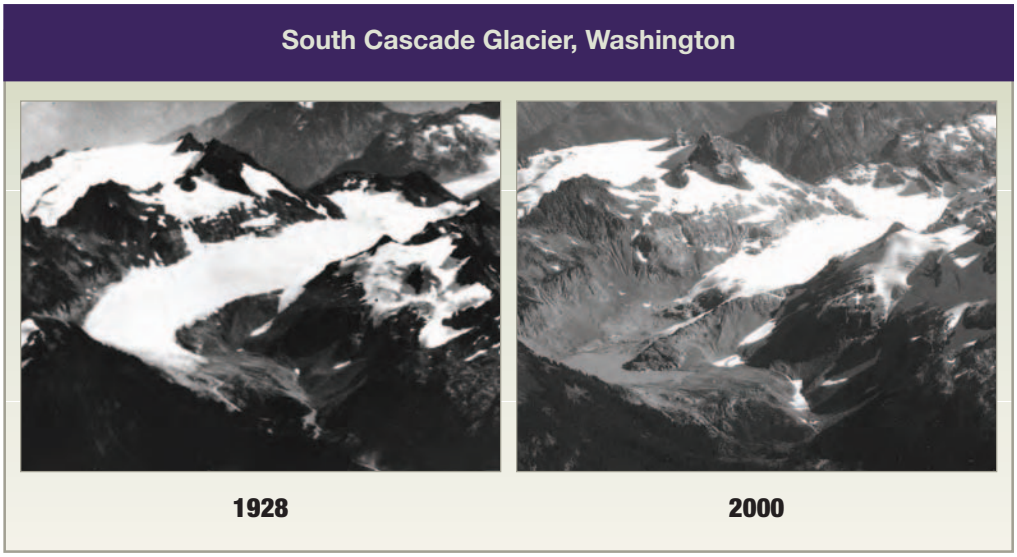


Figure 10: Changing Glacier Mass Balance. Mid-latitude glaciers respond quickly and dramatically to fluctuations in climate. Aerial views of South Cascade Glacier, Washington, in 1928 and 2000, illustrate the magnitude of glacier wastage (negative mass balance) and the terminus retreat that has been characteristic of glaciers in the region. Over this time span, the glacier has lost half its volume and retreated 1.5 km. *Credit: USGS.*

New North American Assimilation System and Reanalysis.[13] Knowledge of the land surface states (e.g., soil moisture, snowpack, evaporation) and the ability to model these states have been major focus areas of CCSP-supported research. The North American Land Data Assimilation System project has created a 1/8-degree modeling system over the continental United States that provides this important land surface information for the purpose of initializing weather and climate models (see <ldas.gsfc.nasa.gov/LDAS8th/LDASdocs/Mitchell2003JD003823.pdf>).

North American Regional Reanalysis.[12] A 25-year North American Regional Reanalysis (NARR; see <wwwt.emc.ncep.noaa.gov/mmb/rreanl>) of historical climate data, covering the period October 1978 through December 2003, was completed in 2004. The regional reanalysis provides a wide range of high-resolution, daily water cycle analysis products such as precipitation, relative humidity, soil moisture, and snow data fields for the 25-year period at 32-km grid scale over North America. The NARR represents advances in regional models and data assimilation that include assimilation of precipitation, direct assimilation of radiances, additional data, and recent developments in modeling, particularly land-surface components. The NARR is a major improvement in both resolution and accuracy over previous reanalysis products.

Global Energy and Water Cycle Experiment – Coordinated Enhanced Observing Period. With support from CCSP agencies, the international Global Energy and Water Cycle Experiment (GEWEX) has coordinated modeling activities and production of new data sets to aid water cycle research. A major GEWEX initiative, the Coordinated Enhanced Observing Period (CEOP; see <www.gewex.org/ceop.htm>), has brought together global observations and model outputs in a consistent framework

and provided them to researchers through the Internet. These integrated data sets have enabled new efforts to determine whether the water cycle is accelerating as a result of global change. CEOP is an example of the type of international coordination needed to support the Global Earth Observing System of Systems.

Coupling between Soil Moisture and Seasonal Precipitation.[8] A project supported by CCSP and performed by the GEWEX Global Land/Atmosphere System Study compared climate models to determine the influence of soil moisture on the ability of the model to predict seasonal precipitation and temperature. Although the models differed in the strength of the simulated coupling between soil moisture and precipitation, they were consistent in identifying areas around the globe where knowledge of soil moisture conditions led to enhanced seasonal climate prediction capability (see Figure 11).

International Cooperation on Integrated Global Water Cycle Observations. A CCSP-supported report, *The Integrated Global Water Cycle Observations Theme* (see <ioc.unesco.org/igospartners/Water.htm>), was developed under the framework of

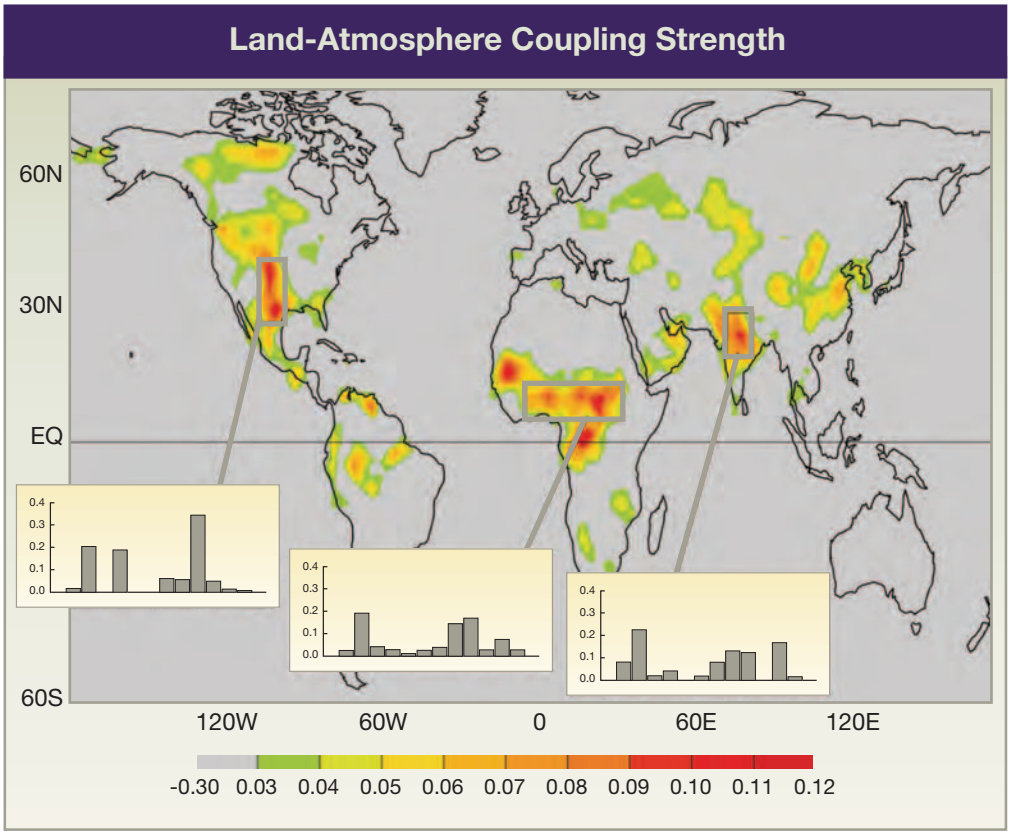
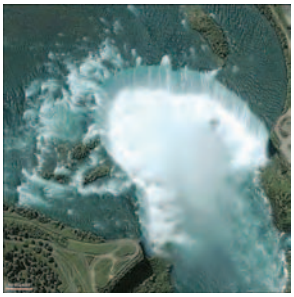


Figure 11: "Hot Spots" where Soil Moisture Changes can Affect Rainfall. The red areas are "hot spots" where soil moisture changes can affect rainfall, according to a multi-model study. The bars in the insets show the individual results for 12 climate models, averaged over the indicated regions. According to the insets, the models clearly do not show perfect agreement in the "strength" of the hot spots. Still, many independent models place the hot spots in the same place. The results pertain to Northern Hemisphere summer months June, July, and August. Red areas show the strongest connection between soil moisture and rainfall. The units for the insets are the same as those for the color bar. *Credit: The GLACE Team (Koster* et al.*, 2004).*

the Integrated Global Observing Strategy Partnership and issued in 2004. The report provides a framework for guiding decisions on priorities and strategies for water cycle observations. It also promotes strategies to facilitate the acquisition, processing, and distribution of data products needed for effective management of the world's water resources. The report was developed following extensive international review and workshops held in the United States, Europe, and Japan, and was co-funded by CCSP and the Japan Aerospace Exploration Agency.

Highlights of Plans for FY 2006



In FY 2006, priorities of the CCSP global water cycle research element include continuing U.S. and global observations; field campaigns and experiments; improvements to data integration and analysis systems; diagnostic and prediction model development; and applications to decision-support systems. Several promising results from prior research will be further explored with an aim to provide this knowledge to applications that provide national and global societal benefits. Concurrently, a cohesive research strategy will be implemented to improve the current deficiencies in understanding that exist regarding many aspects of the regional and global water cycle. The program outlined for FY 2006 will lead to near-term improvements in planning, decisionmaking, and resource management activities – a major aim of the program. However, significant unresolved research issues will require longer term effort. To address such research and applications needs, several key initiatives will be launched in FY 2006.

National Hydrological Observatories: Implementing the First of a Network of Comprehensive Observatories for Watershed Data. The Consortium of Universities for the Advancement of Hydrological Science, Inc., is initiating, with assistance from CCSP agencies, planning for the development of basin-scale observatories to support research in hydrology and related sciences. The long-term goal is to establish an integrated network of "hydrological observatories" to bring together hydrological, limnological, meteorological, chemical, ecological, microbial, and other data on soils, landscapes, waterways, wetlands, and lakes, to support researchers probing the integration of watershed processes at scales of thousands of square kilometers. The initial goal is to place watershed data being collected by a wide variety of organizations into a common framework for easy access by all for interdisciplinary research and water resources management. Gaps in current research and operational observing systems will be filled by adding complementary measurements so as to better quantify atmospheric, surface, and subsurface processes in the water cycle, including transport and transformation of chemical species. Progress is being

made toward establishing supporting infrastructure and awards will be made in FY 2006 for testing major issues in observatory design.

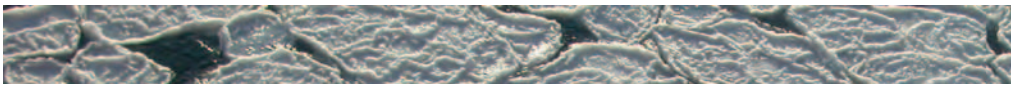
These activities will address Questions 5.1, 5.2, 5.3, 5.4 of the CCSP Strategic Plan.

Tropical Warm Pool International Cloud Experiment: Improving Understanding of Key Water Cycle Processes. Cirrus clouds are ubiquitous in the tropics and have a large impact on their environment, but the properties of these clouds are poorly understood. A measurement campaign focusing on cirrus clouds is being planned for the region around the Atmospheric Radiation Measurement site in Darwin, Australia, during January-February 2006. The Tropical Warm Pool International Cloud Experiment (TWP-ICE) will employ multiple research aircraft, launch balloon-borne meteorological sensors from an array of sites, and extend the spatial sampling of the Darwin region with additional surface sites (see Figure 12). TWP-ICE will provide a picture of cloud conditions with unprecedented detail for the deep tropics. The data set produced through this effort will be used to evaluate how existing models simulate cloud properties and to improve those models. TWP-ICE has been developed through collaboration among a variety of institutions from the United States (including DOE and NASA), Australia, Europe, Canada, and Japan.

These activities will address Questions 5.2 and 5.3 of the CCSP Strategic Plan.

Tracking Changes in National and Global Water Resources. Promising preliminary research results from the Gravity Recovery and Climate Experiment (GRACE) satellite, a joint U.S.-Germany mission, will be expanded in 2006 to quantify changes in regional water storage (reservoirs and groundwater). In 2004, seasonal and year-to-year changes in water storage at subcontinental scales were identified from GRACE observations, and agreed with best estimates from Land Data Assimilation Systems. GRACE observations, together with advanced gravity anomaly models, provide a powerful new tool to track surface water fluxes from one place to another, and to assess how these fluxes influence climate, weather, and water resource availability. In the past, the measurement of water in large, inaccessible river basins has not been reliable and fluxes in underground aquifers and deep ocean currents have been nearly impossible to measure. Observations of regional mass variations of water on land and in the oceans will assist in interpreting annual signals in long-term sea-level change that have become an important indicator of climate change. Similarly, changes in regional groundwater will provide critical observational "closure" constraints to hydrological models used for water resources management.

These activities will address Questions 5.1, 5.3, 5.4, and 5.5 of the CCSP Strategic Plan.



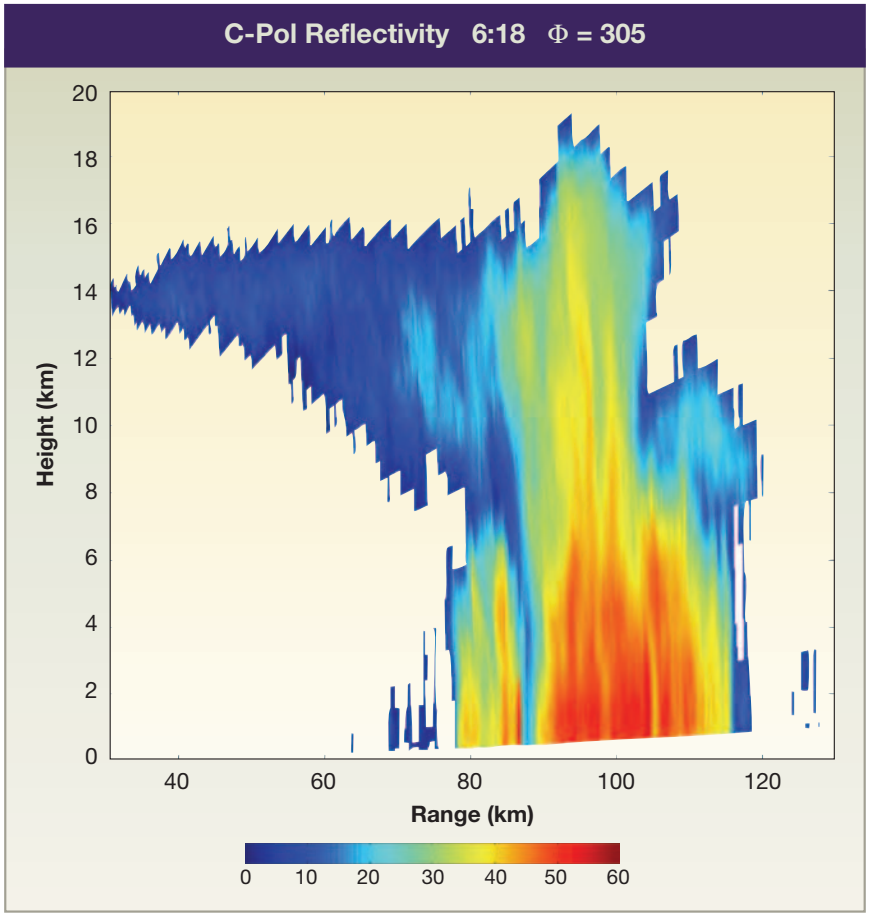


Figure 12: Build-Up to the Wet Phase of the Australian Monsoon. During the wet phase of the Australia monsoon (Dec-Feb) and the build-up to the wet phase (Nov), convection is a common occurrence at Darwin. This image from the centimeter-wavelength radar operated at Darwin illustrates the intense convection that typifies the monsoon build-up period. Such convection may exhibit strong updrafts (reds and yellows in the image) reaching altitudes of 18 km or greater. Convection during the active wet phase of the monsoon exhibits weaker updrafts more representative of oceanic conditions. During TWP-ICE both types of convection will be encountered, providing a means of relating cloud properties to convective strength. *Credit: P. May, Australian Bureau of Meteorology Research Centre.*

Synchronized Measurements to Address Key Uncertainties Associated with the Water and Energy Cycles. With the launch of CALIPSO, CloudSat, and PARASOL, the satellite constellation designated the "A-Train" – composed of those satellites and Aqua and Aura (see Figure 28 in the "Observing and Monitoring the Climate System" chapter later in this volume) – will provide an unprecedented opportunity through FY 2008 for the Earth science community to utilize satellite data to evaluate and improve components of Earth system models. These different instrument platforms, flying in the same orbit minutes apart, will provide multi-platform observations of water and energy cycle processes. The A-Train will be a demonstration of the technological capability to obtain nearly co-located, time-synchronous measurements from a suite of satellites. Teams of scientists have been assembled to take advantage of this unique opportunity. Some of the specific issues that will be addressed are cloud formation/dissipation processes, aerosol-cloud interactions, and cloud-radiation feedback, which are major sources of uncertainty in climate models.

These activities will address Goal 1 of the CCSP modeling strategy and Questions 4.1, 4.2, 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

Monitoring Global Tropical Precipitation: The Heat Engine that Drives Global Atmospheric Circulation. The Tropical Rainfall Monitoring Mission (TRMM) satellite will be extended well beyond its design life of 3 years to 2009, thereby providing continued active radar coverage of global tropical rainfall and cloud structure. TRMM, launched in 1997 with the first space-based precipitation radar together with a co-located TRMM Microwave Imager (TMI), among other instruments, has worked flawlessly and provided substantially improved data about cloud structure and new processing algorithms for passive microwave instruments aboard other satellites [e.g., the Special Sensor Microwave/Imager (SSM/I)]. Progressively improved algorithms derived from TRMM research will continue to be used to reprocess SSM/I data from previous (20+) years to obtain more accurate estimates of global tropical precipitation climatology and time series of tropical precipitation variability and change. Also being explored are requirements for a follow-on "operational" satellite system to provide data comparable to TRMM and to enable the optimal use of data from the Global Precipitation Mission (GPM). GPM represents the next-generation follow-on research spacecraft to TRMM, planned for launch by the end of the decade.

These activities will address Questions 5.1 and 5.3 of the CCSP Strategic Plan.

Observing and Resolving Soil Moisture: A Critical Uncertainty in Earth/Climate Models and Operational Applications. A new thrust in the Second Global Soil Wetness Project (GSWP-2) under the rubric of the international GEWEX Modeling and Prediction Panel is to better link land-surface modeling with remote-sensing applications. This will be done by expanding the validation and assimilation capabilities of current Land Surface Schemes (LSS) at a spatial resolution of about 1 degree (~100 km) beyond the few years where *in situ* data are readily available. LSS will continue to be examined for their ability to simulate brightness temperature, assessed by comparing airborne measurements from several large-scale campaigns held during GSWP-2. Such an assessment is a prototype of LSS validation on a global scale, which is necessary for taking advantage of future satellite-based L-band radiometry from NASA's HYDROS satellite mission, the European Space Agency's Soil Moisture-Ocean Salinity mission, and the NASA Aquarius (ocean salinity/soil moisture) mission. HYDROS offers the unique advantage of carrying both active and passive microwave instruments.

These activities will address Questions 5.1, 5.2, 5.3, 5.4, 5.5 of the CCSP Strategic Plan.

Synergistic Observations, Research, and Modeling: Bedrock to Boundary Layer and Beyond. One of the roadblocks to enhancing water cycle understanding is the lack of comprehensive coincident measurements of all aspects of the continental water cycle. This includes observations of subsurface hydrology (groundwater to the bedrock, soil moisture, and chemistry), the land surface (e.g., runoff, vegetation and evapotranspiration, surface exchange fluxes of heat, momentum, and moisture, and

radiation balance), the atmosphere (e.g., water vapor, winds, thermodynamics, cloud radiative forcing, and precipitation), and water consumption, distribution, and quality, among others. In FY 2006, the Science Steering Group for the CCSP global water cycle research element and the broader science community will develop an "integrating" strategic implementation plan to address these issues. The plan will be one of the central features of CCSP's implementation of the water cycle science component, and will outline a strategy for achieving near-term priorities while laying the groundwork for targeting longer term goals. Observing systems will be designed within the construct of a seamless modeling framework, and associated data and information synthesis and management systems. The outcome of this research, spanning the next decade, will be an essential part of an integrated end-to-end approach to help apply operational and research-based water cycle observations, model predictions, and data assimilation products to decision-support tools that are developed and used by the operational applications community, including planners and managers of natural and economic resources.

These activities will address Questions 5.1 through 5.5 of the CCSP Strategic Plan.

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4 Land-Use and Land-Cover Change

Strategic Research Questions

6.1 What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?

6.2 What are the primary drivers of land-use and land-cover change?

6.3 What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?

6.4 How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?

6.5 What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

See Chapter 6 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Land use and land cover are linked to climate and weather in complex ways. Key links between land cover and climate include the exchange of greenhouse gases between the land surface and the atmosphere, the radiation balance (both solar and long-wave) of the land surface, the exchange of sensible heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere.

Because of these strong links between land cover and climate, changes in land use and land cover are important contributors to climate change and variability. Reconstructions of past land-cover changes and projections of possible future land-cover changes are needed to understand past climate changes and to project possible future climate changes. Land-cover characteristics are important inputs to climate models. In addition, changes in land use and land cover affect ecosystems, biodiversity,

and the many important goods and services they provide to society, including carbon sequestration. One focus of FY 2006 land-use and land-cover change (LULCC) projects will be to provide large-scale biomass estimates and forest cover assessments for carbon models.

Determining the effects of land-use and land-cover change on the Earth system depends on an understanding of past land-use practices, current land-use and land-cover patterns, and projections of future land use and cover, as affected by human activities, population size and distribution, economic development, technology, and other factors. Land-use models and innovative methods for projecting land-use and land-cover patterns and characteristics into the future (5 to 50 years) will be a subject for a special overview workshop at the National Academy of Sciences.

The combination of climate and land-use change affects the Earth's environment in more significant ways than either acting alone. While land-use change is likely a driver of environmental and climatic changes, a changing climate can, in turn, affect land use and land cover. Climate variability alters land-use practices differently in different parts of the world, highlighting differences in regional and national vulnerability and resilience. In FY 2006, U.S. LULCC research will examine such regional heterogeneities both in the United States and internationally.

The interaction between land use and climate variability is poorly understood and will require the development of models linking the geophysics of climate with the socioeconomic drivers of land use. Providing a scientific understanding of the process of land-use change, the impacts of different land-use decisions, and the ways that decisions are affected by a changing climate and increasing climate variability are priority areas for research. In addition to being a driver of Earth system processes affecting climate, the carbon cycle, and ecosystems, land-use and land-cover change are global changes in their own right, requiring a separate research foundation. CCSP research in this area in FY 2006 will include a focus on improving multi-sector models for land-use change, and on improving models that relate climate change, population density, and land use and cover to regional water availability.

Highlights of Recent Research

Selected highlights of recent research supported by CCSP participating agencies follow.

Projecting Area Changes for Major Forest Types.[1] Modeling the dynamics of forest cover changes is part of the periodic national forest resource assessments by the USDA Forest Service and cooperators. One of the largest changes in U.S. forest type areas over the last half-century has involved pine forest types in the South. The area of planted pine has increased more than 10-fold since 1950, mostly on private lands. Baseline projections indicate a net increase of about 5.6 million ha (about 13.8 million acres), which is approximately a 52% increase in planted pine area in the South over the next 50 years. This forest investment is expected to result in a significant increase in sequestered carbon per acre. With increasing amounts of timber harvests arising from plantations, this will also affect carbon storage in wood products. U.S. forests elsewhere will also continue to change in structure and composition, as the area of timberland with trees older than 150 years on National Forest lands is projected to more than double by 2050. Many of those forests are in the Pacific Northwest and can lead to a notable increase in sequestered forest carbon.

Population, Land Use, and Climate Change Impacts on Regional and Local Water Supply and Demand.[12] Forest Service scientists assessed the effects of model-projected climate change scenarios coupled with potential changes in population, hydrology, and land use/land cover to examine future water supply and demand across the southern United States. Long-term average, maximum, and minimum water yield and demand were examined. Water yield reflects the combined influences of vegetation, soils, precipitation, temperature, and evaporation. The study found that current water yield exceeds water demand by more than 100 times during an average precipitation year in the region. However, some local areas are currently experiencing significant water shortages due to high population density, water demand, and/or periodic drought. Overall, the climate projections suggest that total water yield will increase in the region over the next 20 years. Local water shortages are projected to increase and expand in area during the next 20 years, with population change having the greatest impact on local water supply stress. Projected changes in climate and vegetative cover will have larger region-wide impacts on water yield, but relatively little impact on local changes in water supply stress compared to population change (see Figure 13).

Lowland Forest Loss in Protected Areas of Indonesian Borneo.[3] Analysis of lowland forest loss in protected areas of Indonesian Borneo (Kalimantan) demonstrates progress toward understanding how complex histories of land use, land cover, policy,

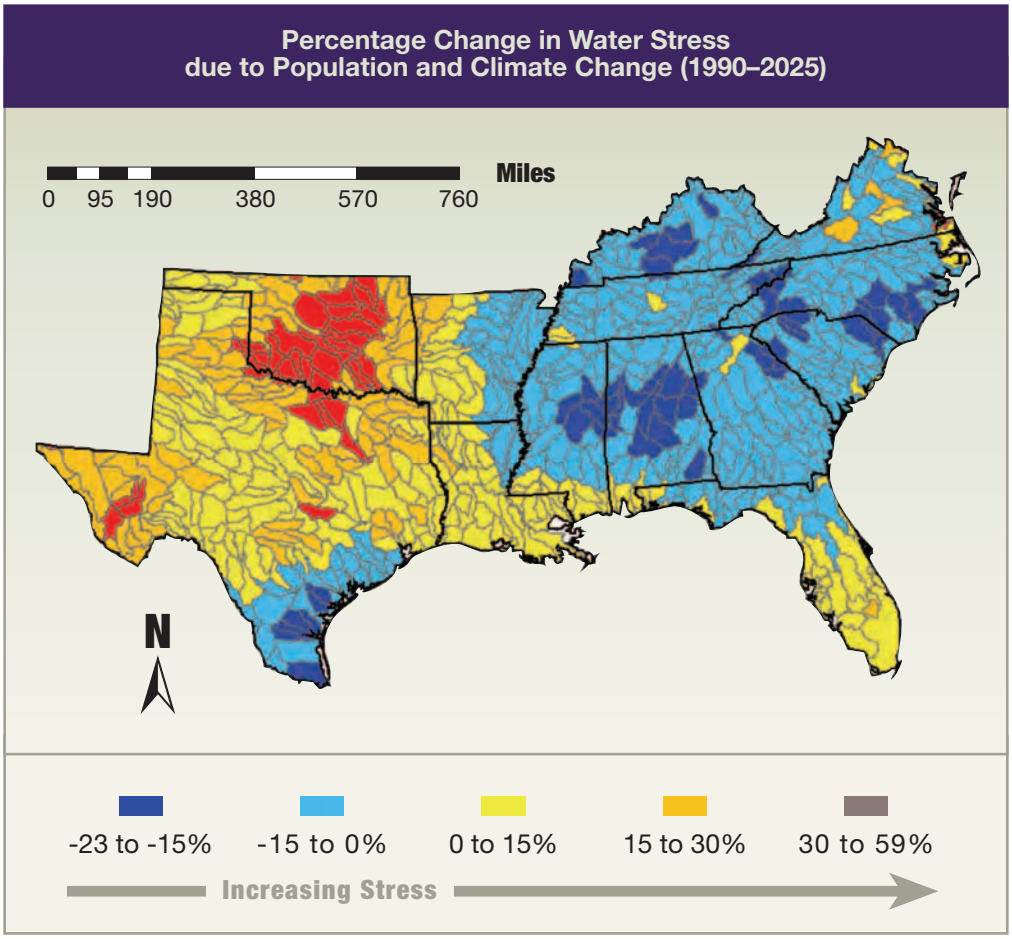

Figure 13: Percentage Change in Water Stress. Projection of effects of changes in population and climate on changes in water stress between 1990 and 2025. This projection used the Hadley 2 Climate Model with sulfates included to project precipitation and air temperature out to 2025; U.S. census demographic projections to 2025; and 1992 Multi-Resolution Land Characteristics (MRLC) vegetation data. *Credit: S. McNulty, USDA/Forest Service.*

and sudden economic change can result in rapid change in land cover. These findings will contribute to improved ecosystem modeling. Satellite remote sensing of land-cover change between 1985 and 2001 reveals rapid and pervasive deforestation of lowland forests within protected areas: a 56% loss (>29,000 km^2) was documented across Kalimantan. Socioeconomic and political drivers of these land-use changes were examined for the period 1970 to 2002. The collapse of logging concession timber stocks through overexploitation, coupled with high demand for timber by wood-based industries and policies that promote oil palm plantations, drive both illegal logging and forest clearing. In combination, these land-use changes result in lowland forest fragmentation and loss of wildlife habitat (see Figure 14).

Results of this research are being applied to verify forest inventories, update estimates of tropical carbon emissions dynamics, and assess effects on biodiversity. In Indonesia, these products are being used by nongovernmental organizations, multilateral donors, and governmental agencies to increase transparency, accountability, and management in remote frontier areas with the aim of reducing illegal logging.

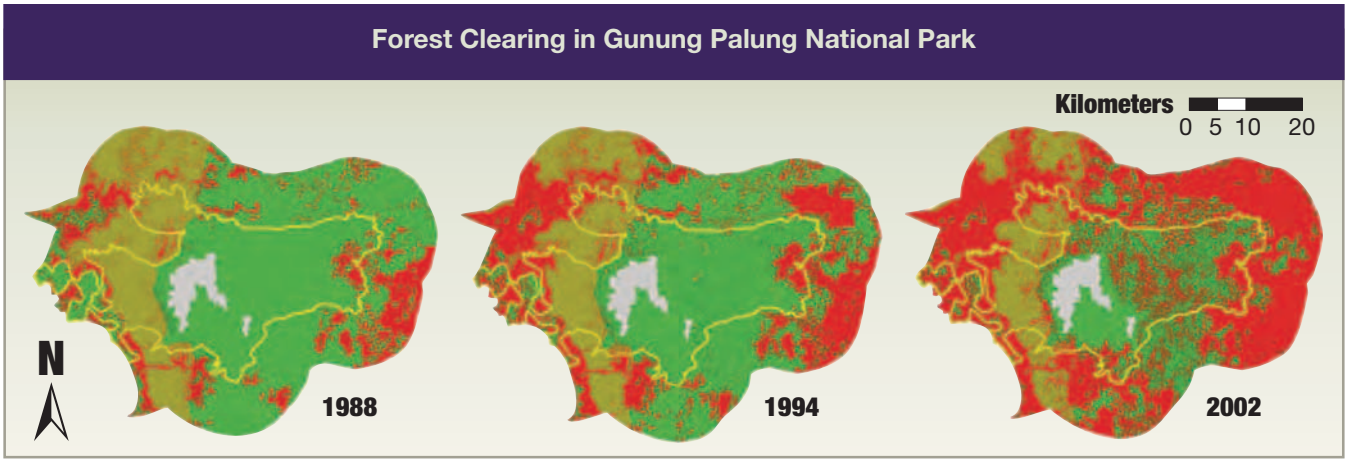

Figure 14: Forest Clearing in Gunung Palung National Park, 1988–2002. Cumulative forest loss within the Gunung Palung National Park boundary (yellow line), Indonesia, and its surrounding 10-km buffer. Forest and non-forest classifications are based on Landsat Thematic Mapper time series. Lowland (green) and peat (olive) forests were converted to non-forest (red), first predominantly in the buffer and later within the park. Grey areas are montane forest and excluded from the analyses.
Credit: S.N. Trigg, University of Maryland (from Curran et al.*, 2004).*

Simulating Urban Development in the Baltimore-Washington, D.C., Area.[2,7,11] Using an existing urban model, scientists simulated patterns of urban development in the Baltimore-Washington, D.C., area. Empirical calibration of the model using Landsat Thematic Mapper image maps of past change between 1986 and 2000 provided calibration of the model using fine-scale data, and refined model projections of future change. The data set also enabled an extensive sensitivity analysis of the model. To serve regional planning needs, the multi-agency Chesapeake Bay Program is now supporting the creation of 30-year projections for the entire Bay watershed that will inform vulnerability assessments and decision support. These scenarios range from one that assumes a continuation of current growth trends and environmental protection policies, to one that assumes stronger environmental protection on open lands and greater use of mass transit. This research is at the forefront of urban modeling, creating fine-scale projections over large areas, using methods grounded in urban theory and economics, and incorporating satellite remote-sensing products (see Figure 15).

Impervious Surface Area Grid of the United States.[6] The construction and maintenance of impervious surfaces (buildings, roads, parking lots, roofs, etc.) constitutes a major human alteration of the land surface, changing the local hydrology, climate, and carbon cycling. The United States is adding impervious surface area at a rapid pace. Population is increasing at a rate of 3 million people per year. Annual U.S. public and private sector construction spending is greater than $480 billion. This includes more than one million new single-family homes and more than 10,000 miles

of new roads per year. Given these trends, impervious surface area is likely to become a more prominent environmental and growth management issue in the coming years. However, few areas have mapped impervious surface area, due in part to the technical challenges and cost constraints of using high spatial resolution (e.g., 1-m) data for direct mapping of constructed surfaces. As an alternative, existing national coverage data sources have been used to model the percent cover of impervious surface area on a 1-km grid for the conterminous United States. The data sources included satellite-observed nighttime lights, three classes of Landsat-derived urban land cover, and U.S. Census Bureau road vectors. The results indicate that total impervious surface area of

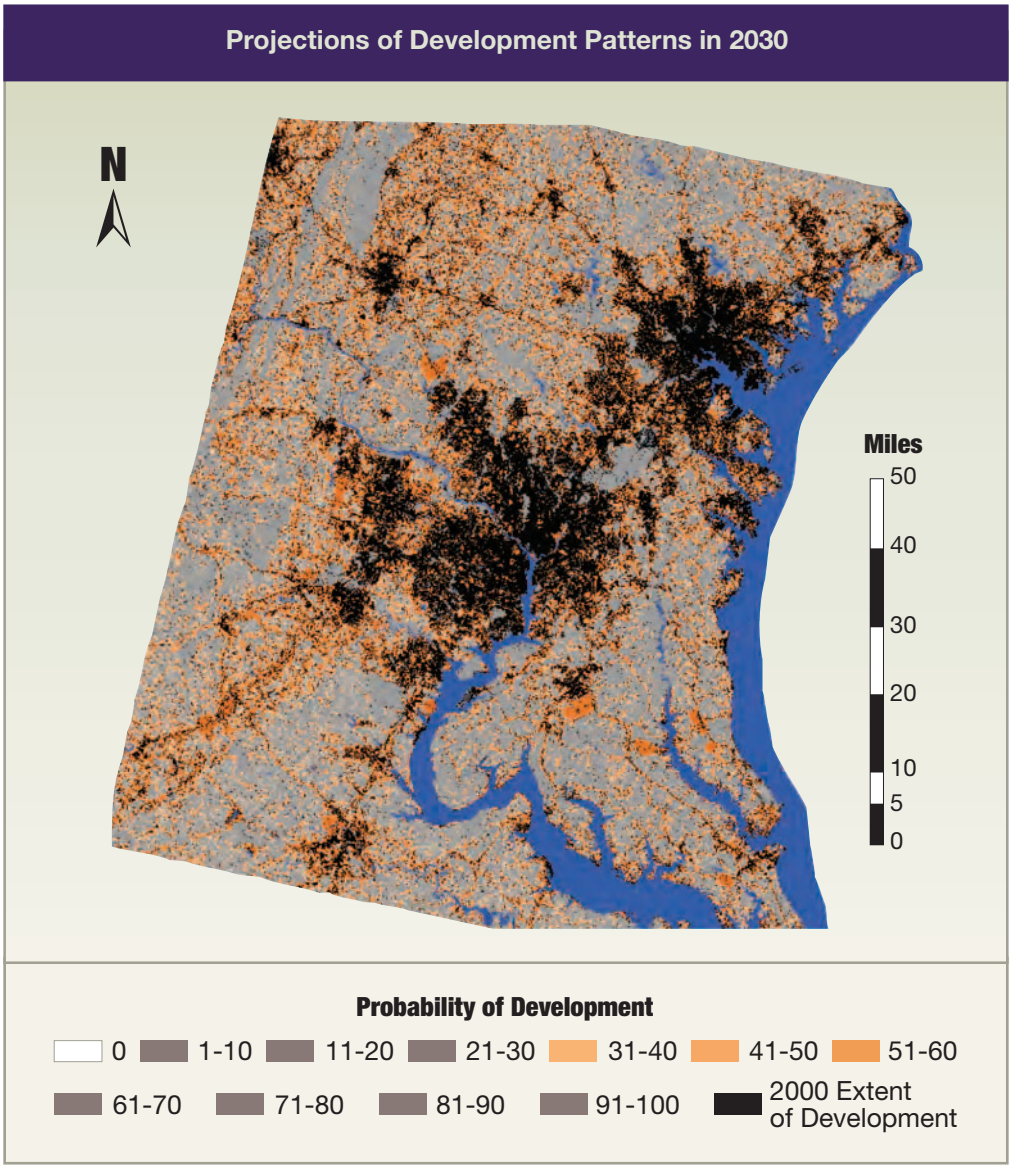

Figure 15: Percentage of Development Patterns in 2030. Using a cell-based urban model (SLEUTH), projections of development patterns in 2030 were created assuming three different policy scenarios (current trends, managed growth, and low growth). SLEUTH was calibrated using Landsat-derived maps of the built environment that documented development patterns between 1986 and 2000. This data set provided a baseline that the calibrated model used to extrapolate patterns into the future. Following business-as-usual patterns of low density and dispersed development, this model projects that the amount of developed land could increase 123%, putting at least 1,300 km^2 of forests and 1,537 km^2 of agricultural lands at risk. *Credit: C. Jantz and S. Goetz, The Woods Hole Research Center.*

the 48 states (and D.C.) is 112,610 (±12,725) km^2, which is slightly smaller than Ohio (116,534 km^2; see Figure 16).

Modeling Global Change Impacts on Wildfire Cycles.[8] A Geographic Information System (GIS) model (FCS-1) has been developed to enable research on how the combined impacts of climate, fire, and human activities influence the nature, distribution, and intensity of fire risk at scales relevant to management concerns and needs. FCS-1 was developed with the recognition that strategic land management requires an understanding of fire behavior and community needs over time. The model incorporates traditional fire science with the human dimension of landscape management in order to identify assets (e.g., property and recreation opportunities) at risk in case of fire. A study utilizing this model emphasized evaluation sessions involving both experts and community members. The evaluation sessions provided valuable opportunities to improve scientific understanding of (a) the ways in which models like FCS-1 might be employed in strategic planning activities to address fire risk problems, and (b) the levels of confidence held by decisionmakers, scientists, and

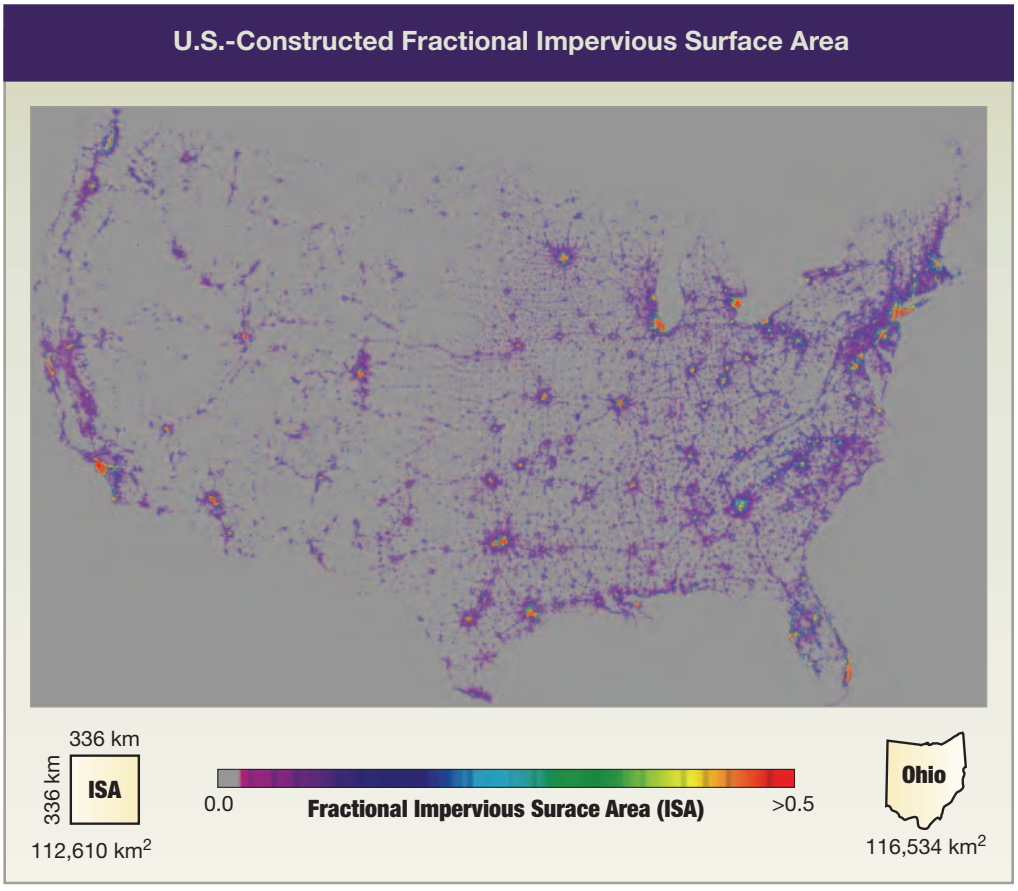

Figure 16: Fractional Impervious Surface Area. The U.S.-constructed impervious surface area (ISA) in 2000 was nearly the size of Ohio. Population is increasing at a rate of 3 million people per year. Annual U.S. public and private sector construction spending is greater than US$480 billion. This includes more than a million new single-family homes and more than 10,000 miles of new roads per year. *Credit: C.D. Elvidge, NOAA/National Geophysical Data Center.*

community members in the various types of scientific information contained in the model.

Establishing the Effects of the Soviet Union's Collapse on the Onset of Spring across Kazakhstan.[4,5,10] Agricultural policies in centrally planned economies of the Soviet Union left enduring legacies of land-surface transformations across eastern Europe and northern Eurasia. The collectivization efforts of the 1930s and 1950s reorganized the land-patch dynamics of cultivated landscapes. The collapse of the economic and political institutions of the Soviet Union at the beginning of the 1990s led to widespread agricultural de-intensification, land abandonment, loss of livestock, and decreased grazing pressure. Mixed into the record of satellite observations of the vegetated land surface are multiple sources of variation: seasonality, interannual climatic variation, changes in observing sensors, and human activity, including land-use/land-cover change. Methods were developed to differentiate the influences of human activities from the other sources of variation at a spatial scale appropriate to link with mesoscale meteorological models. The research focused on Kazakhstan, the ninth

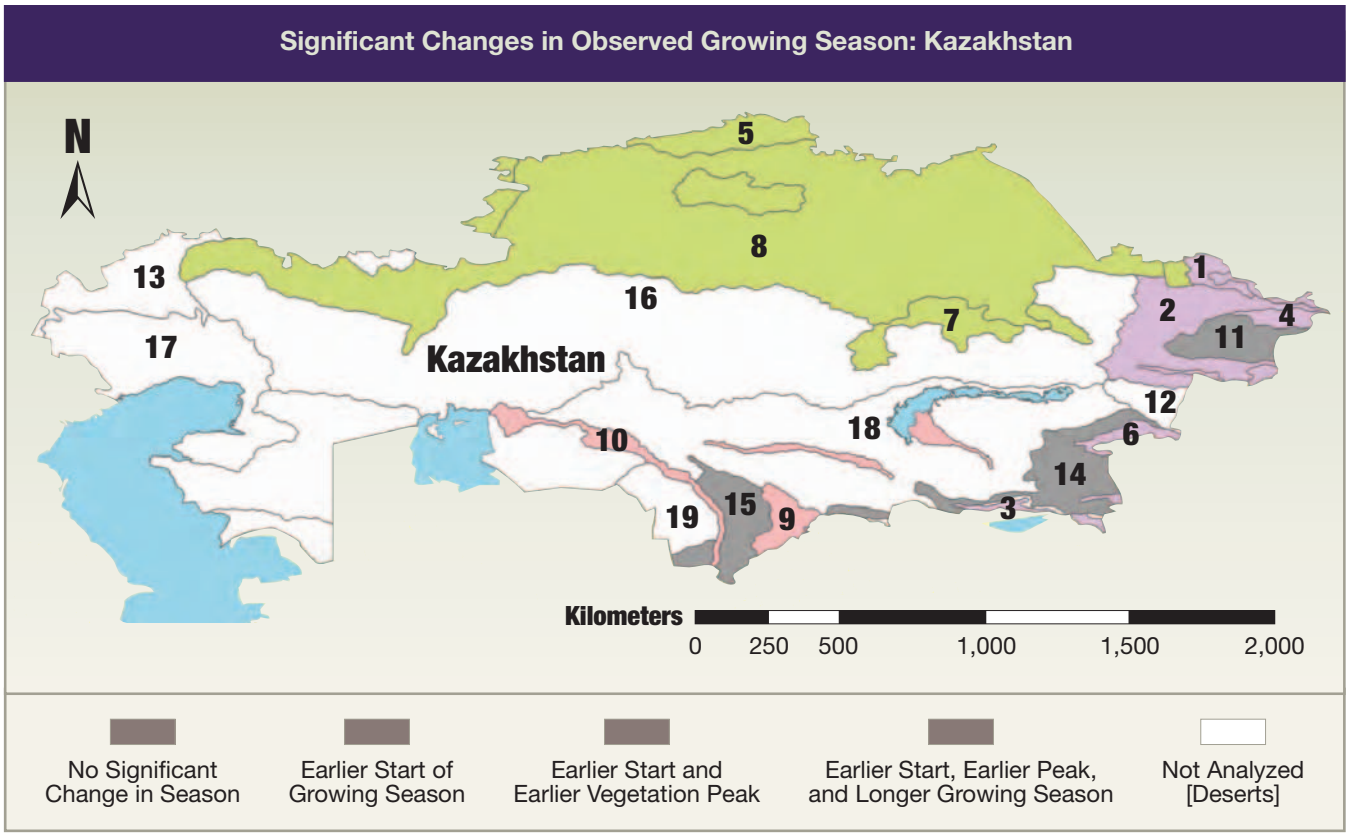

Figure 17: Significant Changes in Observed Growing Season: Kazakhstan. Significant changes in growing season have been detected in many of the 19 ecoregions across Kazakhstan. *Credit: G. Henebry, University of Nebraska-Lincoln*.

largest country in the world in land area, spanning both semi-arid to arid regions dominated by dryland agriculture and grazing, providing an excellent example of post-Soviet land-use/land-cover change. Of the nineteen ecoregions in Kazakhstan, twelve exhibit strong spring seasonality. Nine of those twelve have shown significant changes in growing season vegetation dynamics when comparing the 1980s under the Soviet regime with the late 1990s (see Figure 17). These change analysis methodologies are transferable to other regions dominated by temperate vegetation.

Synthesis of Land-Cover and Land-Use Research.[9] A synthesis of work carried out under the auspices of NASA's Land-Cover and Land-Use Change Program over the past 8 years was published in 2004. This program involves hundreds of scientists who have worked to understand human impacts on land cover, which is one of the most important forces changing our planet. The work reported in the volume and accompanying CD spans the natural and the social sciences, and describes the application of state-of-the-art techniques for understanding the Earth. These techniques include satellite remote sensing, geographic information systems, modeling, and advanced computing. The volume includes detailed case studies, regional analyses, and globally scaled mapping efforts.

Highlights of FY 2006 Plans

CCSP will support research to identify, quantify, and understand fundamental processes of land-use and land-cover change and their consequences. One avenue for support of this work is an interagency solicitation that will result in delivery of the near-term (2-year) products addressing aspects of the LULCC science questions outlined in Chapter 6 of the *CCSP Strategic Plan* including detection and monitoring of LULCC processes; LULCC drivers and environmental impacts; and LULCC and climate variability and change interactions. A sampling of other key research plans for FY 2006 is provided below.

Land-Use Change Effects on Carbon Dynamics in Eastern Deciduous Forests of North America. Understanding the role of forests as potential carbon sinks is emerging as a national and global priority. In FY 2005, researchers began investigating the role of recent past, current, and future land-use change on carbon dynamics in eastern deciduous forests of North America. These forests may have played a major role in past carbon dioxide uptake due to regrowth following major cutting at the turn of the previous century. Current rates of timber harvest in eastern deciduous forests are high, so future land-use and -cover changes may again affect carbon cycling. New research will address the interactions between forest management and carbon

sequestration. Research will continue through FY 2007 and the results will help State and national agencies manage forests in the context of future economic and climatic changes.

These activities will address Question 6.2 of the CCSP Strategic Plan.

A New Enhanced Map of Forest Biomass for All Russian Territory. A map will be developed of the forest biomass of all Russia, based on Landsat satellite and 500m- and 250m-resolution Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite products through a combination of classification and modeling and using Russian Forest Inventory data of both high and low spatial resolution. This map will be an improvement over existing products, as no current maps of the forest biomass of Russia exist. The only current data are based exclusively on Russian Forest Inventory data of "unknown and unverifiable" quality and with little spatial detail. After a reliable methodology is developed and tested, this product could be reproduced on a repeated basis allowing the assessment of changes in forest carbon stocks over time.

These activities will address Question 6.1 of the CCSP Strategic Plan.

Global Tropical Forest Assessment. A global tropical forest assessment will be conducted. The current rate of tropical forest loss and degradation is not well quantified. Previous efforts to measure deforestation in the tropics have had to rely on spot checks and sparse sampling. This study will utilize the global archive of more than 10,000 Landsat scenes that have been acquired since 2000. The study will measure, with fine spatial accuracy, deforestation and also logging, which has not been measured before. The results will be validated using a global archive of high-resolution IKONOS images acquired by NASA under the commercial Data Buy Program. The project is being developed within the framework of the Global Earth Observing System of Systems (GEOSS) initiative and in coordination with international programs, including the United Nations Food and Agriculture Organization, the United Nations Environment Programme, and the Global Observations of Forest and Land Cover Dynamics program.

These activities will address Question 6.1 of the CCSP Strategic Plan.

A Basin-Scale Econometric Model for Projecting Future Amazonian Landscapes. A basin-scale econometric model will be developed for use in predicting land-cover change scenarios in the Amazon basin. This model will combine a regional-scale GIS with case studies to project land-cover change over large areas.

It will represent an improvement upon existing aggregate models for the Amazon, and will lead to enhanced projection of land-cover change based on observed historical deforestation in the basin. The empirical approach it employs will also facilitate the evaluation of confidence intervals for model coefficients and independent comparison of model projections.

These activities will address Question 6.3 of the CCSP Strategic Plan.

Mitigation Plan for Landsat-7 Problem. Since 1972, Landsat satellites have collected data that have been invaluable for the quantitative study of land cover, land use, and land-cover change. The ground resolution of the Landsat satellites is ideally matched to study a wide range of surface phenomena. In addition, a variety of natural and human land-use changes, such as wildfires, deforestation, agricultural activity, glacier expansion/contraction, and urbanization represent alterations that also occur at spatial scales of tens of meters. Since June 2003, Landsat-7 data have been substantially degraded by a mechanical failure of the Landsat-7 instrument and there are no other satellite systems available to provide Landsat-type data globally at these spatial scales. While scientists are looking to use other U.S. and international satellite instruments to provide interim land-cover data, a recognized need exists to ensure the continuing availability of high-quality land-cover measurements into the future. The details of an observing strategy to meet this requirement are under discussion now within the U.S. Government. U.S. Government agencies affected by this include NASA, USGS, USDA, EPA, DOD, the Department of Homeland Security Federal Emergency Management Agency (FEMA), and NOAA. The proposed solution for the lack of Landsat-like data is to redirect agency resources to acquire global collections of data from Landsat-5, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), EO-1's Advanced Land Imager, and similar satellites now operated by foreign countries for the period 2005 to 2007. This effort will be organized by NASA and USGS, the two major users of Landsat data, with advice from and participation of other interested CCSP agencies.

These activities will address Questions 4.3, 4.4, and 4.5 of the CCSP Strategic Plan.

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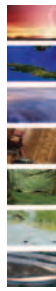


5 Global Carbon Cycle

Strategic Research Questions

7.1 What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.2 What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

7.3 What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?

7.4 How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

7.5 What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?

7.6 How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

See Chapter 7 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

CCSP research on the global carbon cycle in FY 2006 will continue to address questions of how large and variable the dynamic reservoirs and fluxes of carbon within the Earth system are, and how carbon cycling might change and be managed in future years, decades, and centuries. This research is needed to help human societies evaluate their

options for managing carbon sources and sinks to achieve an appropriate balance of risk, cost, and benefit.

Over the past 2 centuries, fossil-fuel emissions, land-use change, and other human activities increased atmospheric carbon dioxide (CO_2) by 30% and methane (CH_4) by 150% to concentrations unprecedented over the past 420,000 years (the time span of the longest fully documented ice core record). Future atmospheric concentrations of these greenhouse gases will depend on trends and variability in natural and human-caused emissions and the capacity of terrestrial and marine sinks to absorb and retain carbon. Options available to societies for stabilizing or mitigating concentrations of greenhouse gases in the atmosphere through management of carbon in the environment involve: (1) reduction of carbon emissions at their source and/or (2) enhanced sequestration of carbon through biospheric storage or engineered approaches.

To address these and related research questions, the United States is focusing its carbon cycle science on targeted research areas that are ripe for scientific progress and that are most relevant to societal concerns. The agencies responsible for CCSP carbon cycle research have organized a coordinated, interagency, and multidisciplinary research strategy to bring together the broad range of infrastructure, resources, and expertise essential for providing this information. This approach involves investigators with atmospheric, oceanic, terrestrial, and human dimensions research expertise and observational, experimental, and modeling skills. These agencies also are establishing an ongoing dialog with stakeholders, including resource managers, policymakers, and other decisionmakers to ensure that information is provided in a useful form.

The North American Carbon Program (NACP), designed to address strategic research question 7.1 (see chapter banner), will continue to be a major priority. The NACP will quantify the magnitudes and distributions of terrestrial, freshwater, oceanic, and atmospheric carbon sources and sinks for North America and adjacent oceans; improve understanding of the processes controlling source and sink dynamics; and produce consistent analyses of North America's carbon budget that explain regional and sectoral contributions and year-to-year variability. The NACP is committed to reducing uncertainties related to the buildup of CO_2 and CH_4 in the atmosphere and the amount of carbon, including the fraction of fossil-fuel carbon, being taken up by North America's ecosystems and adjacent oceans.

The first studies to address the objectives of CCSP's new Ocean Carbon and Climate Change (OCCC) program plan, designed to address strategic research question 7.2, will be initiated in FY 2006. The OCCC program is an integrated effort for oceanic monitoring and research aimed at determining how much CO_2 is being taken up by

the ocean at the present time and how climate change will affect the future behavior of the oceanic carbon sink. NACP and OCCC program interests and objectives converge in addressing carbon dynamics in the coastal oceans adjacent to North America and in the land-sea margins – diverse and variable areas where impacts of changes in the terrestrial environment and climate greatly complicate carbon cycle processes. New investigations of carbon dynamics in the coastal oceans adjacent to North America will address both OCCC and NACP objectives.

Other FY 2006 priorities, focused on reducing scientific uncertainties regarding carbon sources and sinks, are: (1) conducting and reporting on experimental studies to investigate the processes regulating carbon balance in terrestrial ecosystems, and (2) developing and improving global carbon cycle models and coupled carbon-climate models to aid in improving projections of atmospheric CO_2 concentrations and climate.

Highlights of Recent Research

AmeriFlux Network Measures Terrestrial Carbon Sinks and Sources and Identifies Biological Controls.[7,10,18] The AmeriFlux network of research sites measures terrestrial carbon sinks and sources and biological processes that regulate the net exchange of CO_2 between terrestrial ecosystems and the atmosphere [referred to as "net ecosystem exchange" (NEE)]. The measurements show that mature forests are important sinks for atmospheric CO_2 (Hollinger *et al.*, 2004). Disturbances that replace or remove forests can result in the land being a net source of CO_2 for a few years in mild climates or up to a decade in harsh climates while the forests are recovering (Law *et al.*, 2004), after which they may gradually revert to being a sink until the next disturbance. Moist tropical forests are not necessarily strong sinks because some of them have experienced recent mortality events that leave large amounts of decaying plant material that can release more CO_2 to the atmosphere than the forests remove [net source of about 1 tonne per hectare per year (Saleska *et al.*, 2003). Thus, the range of observed annual NEE of CO_2 ranges from a source of about 1 tonne per hectare to a net sink of 2 to 4 tonnes per hectare for forests and about 1 tonne or less per hectare for agricultural crops and grasslands. These results are expected to dramatically improve process depictions in carbon and climate models.

AmeriFlux Measurements Reveal Direct Influence of Volcanic Eruptions on Terrestrial Carbon Cycle.[1,5] The growth rate of atmospheric CO_2 concentration decreased after the explosive eruption of Mt. Pinatubo in the Philippines in June 1991. Scientists have been debating the cause of this atmospheric CO_2 decrease for many years. In a recent study by Gu *et al.* (2003), a group of AmeriFlux scientists found

that aerosols (tiny particles suspended in the air) formed in the aftermath of the eruption altered the quantity and quality of solar radiation for vegetation, and this alteration significantly enhanced photosynthesis under cloudless conditions in a deciduous forest in the United States. These measurements indicate that increased CO_2 uptake by terrestrial vegetation caused by the effects of aerosols from the Pinatubo eruption on incident solar radiation were at least partly responsible for the sudden decline in the growth rate of atmospheric CO_2 concentration after the eruption. The study also indicates that anthropogenic aerosols, which can similarly change the quantity and quality of solar radiation for vegetation, may affect carbon cycling dynamics. A modeling study by Angert *et al.* (2004) suggests an alternate mechanism for the enhanced CO_2 sink in 1992-1993, due to a unique combination of an enhanced ocean CO_2 sink, reduced respiration driven by cooling and drying of the upper layers of the soil thereby reducing heterotrophic respiration, and reduced biomass burning. These studies illustrate the complexity of the global carbon cycle and underscore the crucial need for continued observations to resolve carbon cycle uncertainties.

Impact of Fires on Interannual Variability in Global Atmospheric Trace Gases.[20] Year-to-year changes in the atmospheric concentration of CO_2 and CH_4 are linked to fire activity associated with the El Niño/La Niña cycle. Information on vegetation, precipitation, surface air temperatures, and changes in Earth's radiation,

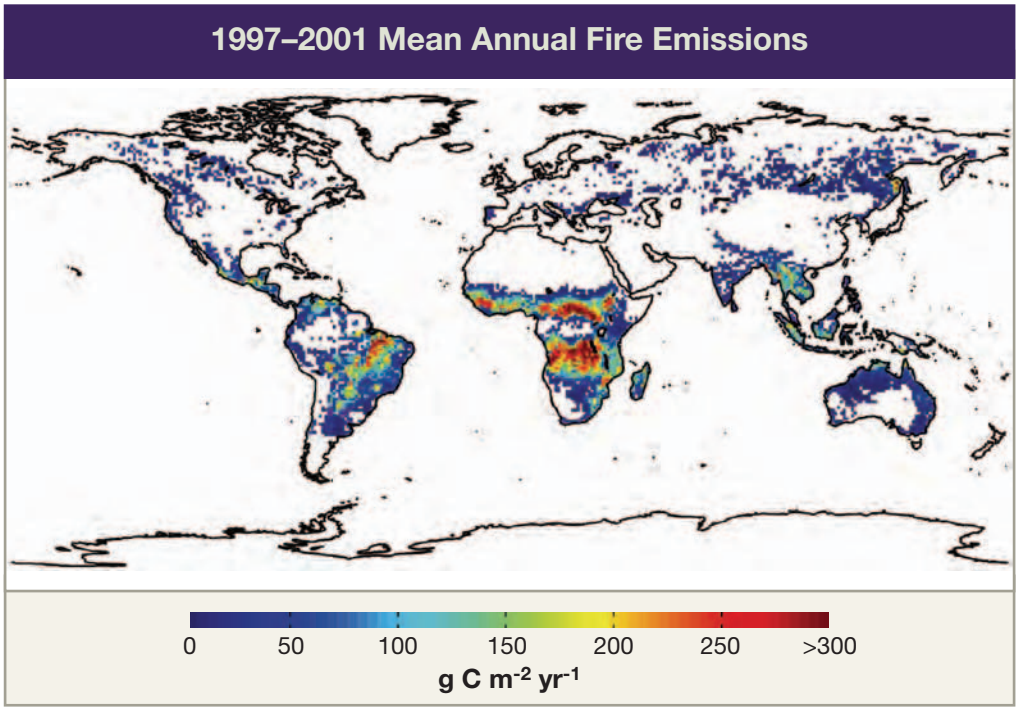


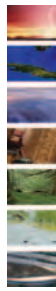
Figure 18: 1997–2001 Mean Annual Fire Emissions. Observations from the VIRS instrument on the Tropical Rainfall Measuring Mission satellite and MODIS instrument on Terra and Aqua satellites provide comprehensive information on the timing and locations of fires. Red to blue indicates high to low emissions of carbon from fires during 1997 to 2001, while white indicates no fires were observed during that period. *Credit: NASA/ Goddard Space Flight Center.*

derived from the Terra, Aqua, Tropical Rainfall Measuring Mission, and Active Cavity Radiometer Irradiance Monitor satellites, was used in modeling analyses of fire effects for 1997 to 2001. Researchers quantified the amount of CO_2 and CH_4 emitted by fires by combining the satellite data with *in situ* measurements of atmospheric gases. Emissions of greenhouse gases from fires increased across multiple continental regions in the El Niño year (1997-1998), including Southeast Asia (60% of the global increase), Central and South America (30%), and boreal forests of North America and Eurasia (10%). Vast areas of the tropics dry out and become vulnerable to fire during El Niño events, thus enabling humans to use fire more effectively as a tool for clearing land. Increases in fires and associated emissions of greenhouse gases are expected if El Niño events increase in frequency and/or intensity in the future.

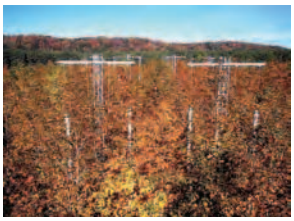
Regionalization of Methane Emissions from the Amazon Basin.[13] The largest single source of CH_4 emissions to the atmosphere is natural wetlands, which account for between 20 and 40% of annual emissions; 60% of this is estimated to come from tropical wetlands, although there is large uncertainty regarding the magnitude and variability of that source. The Amazon Basin contains one of the largest areas of seasonally inundated tropical wetlands. Microwave remote-sensing techniques were used to measure wetland extent and seasonal variability, and the resulting data were combined with results from existing field studies of CH_4 flux in a model to extrapolate CH_4 flux across the entire Amazon Basin. Extrapolation to the Central Amazon Basin (1.77 million km^2 area) produces an estimated 6.8 TgC yr^{-1}, and extrapolation to the full Amazon River Basin below 500-m elevation (5.2 million km^2, of which 17% is wetland) produces an estimated 22 TgC yr^{-1} from CH_4 emissions. This estimate is lower than those previously reported for the region. The satellite data analyses indicate that past studies overestimated the length of time seasonal wetlands were flooded and therefore overestimated annual methane emissions.

Variability in Low Productivity Ocean Gyres.[12] The mid-ocean gyres are huge circulation cells within the major ocean basins. They are vast expanses of very low primary production and biomass. Their low productivity results from the physical dynamics of the circulation within the gyre, which depresses the depths at which significant nutrient concentrations (e.g., nitrate, phosphate, and silicate) required for photosynthesis occur. Global surface chlorophyll concentrations measured over seven years by the U.S. Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Japanese Ocean Color and Thermal Scanner (OCTS) satellite sensors were used to estimate

temporal changes in the size of each gyre. The analysis shows that these areas have a distinct seasonal cycle and that the overall area of the gyres in the North Pacific and North Atlantic expanded during 1996 to 2003, while there was little change in the area of the South Pacific, South Atlantic, and southern Indian Ocean gyres. The study did not attempt to explain why the Northern Hemisphere gyres are expanding and was too short to determine whether the trends will continue. This first-ever quantification of year-to-year variability across the global oceans has implications for carbon dynamics, and raises a concern about whether continued expansion of the low-productivity gyres would reduce the size of the ocean carbon sink. Continuing systematic satellite observations will be available to monitor future trends and address this concern.



Changing Carbon Dynamics in the Oceans.[4,17] The Repeat Hydrography CO_2/Tracer Program is a systematic and global re-measurement of select cross-sections of the ocean to quantify changes in storage and transport of heat, freshwater, CO_2, chlorofluorocarbon tracers, and related properties. For cruises in the North Pacific, difference plots for the 2004 Repeat Hydrography compared with the 1994 World Ocean Circulation Experiment quantitatively document significant changes. Increases in dissolved inorganic carbon (DIC) of up to 35 μmol kg^{-1} were observed in surface waters and in intermediate depths ranging from 200 to 1000 m. On average, mixed layer DIC increases of 1.5 ± 0.2 μmol kg^{-1} yr^{-1} were observed in the subtropical waters of the North Pacific, indicating that over the past decade the oceanic uptake of CO_2 in this part of the global ocean has been faster than the rate of growth of CO_2 in the atmosphere. These results indicate that the rate of uptake of CO_2 may differ significantly in different regions of the global ocean.



Synthesis of Forest FACE Experiment Data.[8,21] Common data sets were assembled from four Free-Air CO_2 Enrichment (FACE) experiments being conducted in forest ecosystems. The ongoing, multi-year experiments were in established stands in North Carolina (loblolly pine) and Tennessee (sweetgum), and in young stands in Wisconsin (aspen-birch-maple) and Italy (poplar). Soil respiration increased in response to CO_2 enrichment, and the relative response was larger in the young stands. The temperature sensitivity of soil respiration was unaffected by CO_2 enrichment. No effects on soil nitrogen pools or processes were observed in the three forest FACE experiments in the United States, indicating that nitrogen limitations are unlikely to constrain increases in forest productivity at similar sites in the initial years following

Figure 19: AmeriFlux Research Tower. Near Howland, Maine, a partnership between the University of Maine, USDA Forest Service, and Woods Hole Research Center provides a platform for studies of ecosystem-atmosphere CO_2 and energy exchange. Instruments visible on the tower include eddy flux instrumentation for measuring net CO_2 and energy exchange [supported by DOE's Office of Science/ Biological and Environmental Research (BER)], a dry deposition and meteorological package for studying air quality (supported by NOAA's Air Resources Laboratory), and a sun photometer for assessing atmospheric aerosols (supported by NASA's Aerosol Robotic Network). Recent results from this and a nearby companion tower have quantified flux measurement uncertainties needed for data-model fusion efforts under the North American Carbon Program (NACP), and have shown that this 140-year-old coniferous forest remains a strong sink for atmospheric CO_2. Researchers operate this site with support from DOE. *Credit: J. Lee, University of Maine*.

CO_2 enrichment. Continued study of these effects over longer time periods will be critical for our ability to predict long-term changes in soil nitrogen availability and the potential for sustained increases in productivity in a CO_2-enriched atmosphere.

Root Dynamics Control Forest Response to Atmospheric Carbon Dioxide.[11,14] Analysis of a nearly continuous 6-year record of fine root production and mortality in an experimental sweetgum forest revealed a large increase in root production and a significant change in the depth distribution of roots in forest plots exposed to a CO_2-enriched atmosphere. These responses, which were measured in a FACE experiment, have important implications for carbon sequestration and nitrogen and water uptake in this and other forest ecosystems. Allocation of carbon to fine roots reduces the potential for carbon sequestration in plant biomass, but increases the potential for carbon storage in soil. Comparison of the responses of the deciduous forest with those in a similar experiment in a pine forest suggests that root system dynamics can explain differences among ecosystems in their response to elevated atmospheric CO_2. These results indicate that accurate assessments of carbon flux and storage in forests must account for the responses of root systems.

Long-Term Forest Management Studies Inform Carbon Management Options.[15] The Long-Term Soil Productivity (LTSP) study seeks to understand how anthropogenic disturbances affect the land's capacity to store carbon through the conduct of a series of 62 long-term field experiments in major forest types of the United States and Canada. This unique study has been in place for more than a decade

and is the largest and most extensive experiment of its type in the world. Results show differences in carbon and nutrient dynamics by soil type and climate regime and provide critical information for developing management systems that maintain and enhance productivity and carbon sequestration options. Findings from studies of alternative fuel treatments for reducing fire risk indicate no significant differences in CO_2 efflux following treatment and provide a basis for local communities to reduce fire risk and improve the health and vigor of forests without affecting greenhouse gas emissions.

Land Resource Management and Reclamation Activities have Significant Potential to Sequester Carbon.[2,3,9,16,19] As noted previously, changes in soil carbon can potentially change the concentrations of greenhouse gases in the atmosphere. If CO_2 from the atmosphere, captured through photosynthesis, is ultimately stored in the soil to a greater degree, the resulting soil carbon sequestration may help slow the rise of atmospheric CO_2. Studies of soil carbon dynamics and storage in a variety of managed systems in the United States and elsewhere have identified and quantified significant carbon sequestration potentials:

- *In situ* measurements and models have determined soil organic carbon (SOC) sequestration potentials for croplands, pastures and rangelands, disturbed lands such as mining areas, natural areas such as wetlands, land in the Conservation Reserve Program (CRP), and urban areas such as lawns, parks, and golf courses. With improved management practices, the potential average rates of SOC sequestration are approximately 70, 40, 60, and 13 Tg of organic carbon annually for cropland, grazing land, forests, and CRP soils, respectively (Lal *et al.*, 2003; USDA, 2004).
- Conversion of cropland to perennial systems in central Iowa increased the SOC content by an average of 11 tonnes per hectare in the upper 35 cm of soil (Cambardella *et al.*, 2004).
- For agroforestry systems in Costa Rica, increased biodiversity resulted in greater soil nutrient supply and carbon storage; plant roots were primarily responsible for soil carbon accrual in these systems. Root organic matter quality, and not the amount of root inputs, best explained effects of species diversity on soil carbon sequestration (Russell *et al.*, 2003).
- Restoration of semi-permanent wetlands in the prairie pothole region of the northern Great Plains increased carbon content in surface sediments (Euliss *et al.*, 2003).

These results are examples of findings that contribute new scientific knowledge about relationships of terrestrial ecosystem processes and management practices on carbon sequestration. Land and resource managers, agricultural consultants, and environmental

organizations are using this new information to foster the development of agricultural and land management systems that mitigate greenhouse gas emissions, enhance soil fertility, and improve soil and water quality.

Climate-Induced Thawing of Permafrost and Implications for Soil Carbon Stocks.[6] The high-latitude regions of North America, including interior Alaska, are critical areas for research because thawing of permafrost within the soil zone can cause a release of carbon to the atmosphere. In the past 40 years, boreal North America has warmed by at least 2°C and has experienced pervasive drying of lakes and water tables. Landscapes with near-surface permafrost store greater than 60% of their carbon stocks in organic soils. While long-term records indicate net carbon storage on land, fires in recent decades have burned these landscapes in unexpected proportions. Trace gas studies at the Bonanza Creek Long-Term Ecological Research Station have revealed complex responses of permafrost landscapes to fire, with post-burn hydrological conditions and plant ecological processes determining the net balance between CH_4 and CO_2 emissions and carbon sequestration. Drought and fire induce complex responses (e.g., water table fluctuation, revegetation patterns) due in part to the discontinuous nature of the permafrost. These findings emphasize the importance of surface and subsurface hydrology for understanding the carbon dynamics of boreal and arctic regions and emphasize the need for baseline studies of carbon cycling on a variety of temporal and spatial scales.

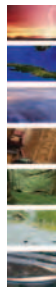
Highlights of FY 2006 Plans

In FY 2006, continuing observations, field campaigns and experiments, and model development will be a priority under the NACP. Significant effort will be devoted to continuing the development, expansion, and optimization of observations and monitoring networks for North American, coastal, and global carbon sources and sinks. The Mid-Continent NACP Intensive Campaign will be completing its initial field phase. New ocean carbon research will be underway in support of the OCCC program, with early emphasis on studies of carbon dynamics in the coastal oceans adjacent to North America that also support NACP objectives. Data management plans and capabilities for NACP and OCCC will be implemented. New experimental studies will be conducted and the results of previous experimental studies will be synthesized to explain the processes regulating carbon dynamics in terrestrial ecosystems, including carbon sequestration. Modeling investigations will focus on improved coupling of carbon-climate models, carbon data assimilation, and better projections of CO_2 emissions and ecosystem responses for climate models. The first *State of the Carbon Cycle Report* is one of the CCSP synthesis and assessment products.

CCSP SYNTHESIS AND ASSESSMENT PRODUCT

The *CCSP Strategic Plan* identifies 21 planned synthesis and assessment products describing the current state of knowledge concerning many different aspects of climate and global change. One of these focuses on the carbon cycle.

North American Carbon Budget and Implications for the Global Carbon Cycle. Synthesis and Assessment Product 2.2 will provide a synthesis and integration of current knowledge of the North American carbon budget and its context within the global carbon cycle. In a format useful to decisionmakers, it will (1) summarize our knowledge of carbon cycle properties and changes relevant to the contributions of and impacts upon the United States and the rest of the world, and (2) provide scientific information for U.S. decision support focused on key issues for carbon management and policy. The report will address carbon emissions, natural reservoirs and sequestration, rates of transfer, the consequences of changes in carbon cycling on land and the ocean, effects of purposeful carbon management, and the socioeconomic drivers and consequences of changes in the carbon cycle. It will include an analysis of North America's carbon budget that will document the state of knowledge and quantify uncertainties. This analysis will provide a baseline against which future results from the North American Carbon Program (NACP) can be compared.



NACP: Measurements and Monitoring. In FY 2006, NACP will continue to assign high priority to global observations by enhancing observational capabilities and monitoring networks for carbon fluxes and stocks in North America and adjacent oceans. The following activities represent major commitments:

- *Regional Carbon Monitoring* – A carbon cycle atmospheric observing system is being built for deployment across the United States in support of research to reduce uncertainty in the North American carbon sink. Small aircraft flown from 24 U.S. sites will collect samples of carbon gases and other trace gases from the surface to about 8-km altitude on a weekly basis. In conjunction with this "vertical profiling," tall communications towers (~500 m) will sample CO_2 and other greenhouse gases continuously from about 12 U.S. sites. This system is expected to be fully implemented by 2007, contingent on availability of funding. The technique will provide critical data for analysis of regional carbon sources and sinks and useful decision-support information for carbon management.
- *Landscape-Scale Carbon Sources and Sinks in Forests* – Current forest monitoring capability lacks many of the observations needed for complete forest carbon accounting over large areas. An improved forest observation and monitoring system that integrates several existing programs is undergoing pilot testing at several forest sites in the United States. Standardized estimates of carbon stocks and flows will provide a strong scientific foundation for development and deployment of carbon sequestration technology to mitigate greenhouse gas emissions. Enhancing observations at experimental forests has additional benefits such as facilitating use of these sites for carbon management research and demonstration projects, and providing the basis for an "early warning" capability to detect the initial impacts of climate change.
- *Landscape-Scale Carbon Sources and Sinks on Department of the Interior Lands* – The recently developed National Carbon Map will be used to identify and quantify the

effects of fire, grazing, and other natural disturbances and human activities on the status and trends of carbon stocks and fluxes. The results will clarify the spatial and temporal dimensions of current U.S. carbon sources and sinks.

- *Measurement of Carbon Cycle Processes in Agricultural Ecosystems* – Process information, carbon flux data, and carbon inventories from agricultural ecosystems will be provided for the mid-continent region of North America. By expansion of the Greenhouse Gas Reduction through Agricultural Carbon Enhancement (GRACEnet) and Agriflux networks, this activity will systematically determine the effects of grazing and cropping on soil carbon and atmospheric CO_2 emissions.
- *Continental-Scale Satellite Data Time Series* – New and continuing investments will be made to produce continental-scale Earth Observing System (EOS) satellite data products for spatial extrapolation of carbon stock and flux estimates. Data products on primary productivity, land cover, and vegetation and phytoplankton properties of North American lands and adjacent oceans will be used to drive carbon and climate models.

- *Coastal Carbon Measurements and Process Studies* – New ocean margin studies will be initiated to determine rates of carbon burial and export to the open ocean, elucidation of factors controlling the efficiency of the solubility and biological pumps in coastal environments, quantification of the influence of coastal marine biogeochemical processes on the chemical composition of open ocean surface waters, and development of coupled physical-biogeochemical models for different types of continental margins

These activities will address Questions 7.1, 7.2, 7.3, and 7.6 of the CCSP Strategic Plan.

NACP: Field Studies. Intensive field campaigns and experimental studies under NACP will feature the following activities in FY 2006:

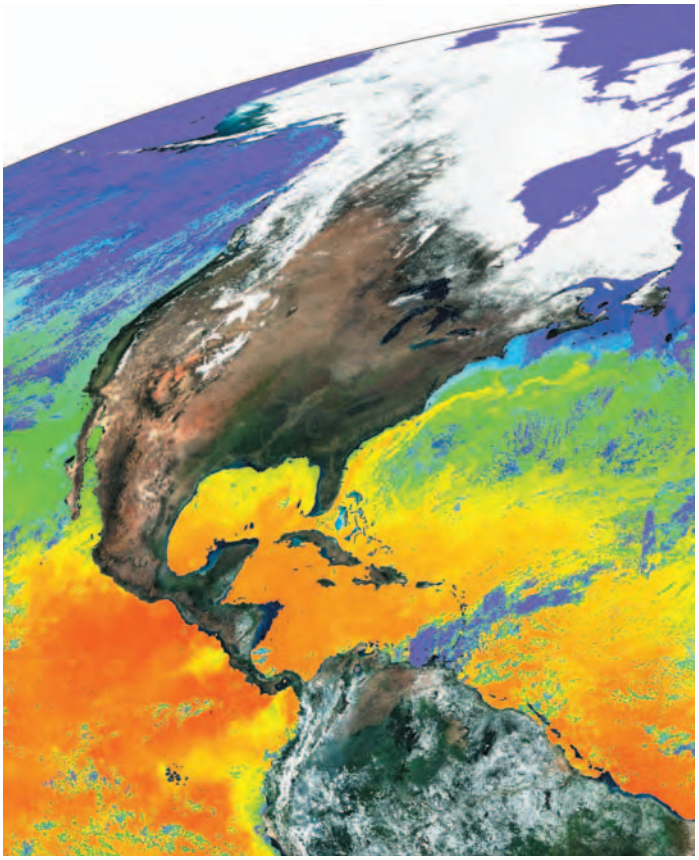
- *Mid-Continent NACP Intensive Campaign* – An intensive field investigation centered on the mid-continent region of North America will develop and test methods for regional and continental estimates of carbon sources and sinks. This study will evaluate and compare two independent approaches for estimating carbon fluxes at the regional scale: the "top-down" approach using atmospheric measurements and models, and the "bottom-up" approach using vegetation and soil carbon inventories, land cover, meteorological information, and models. This prototype study will integrate existing data on crop, forest, and soil carbon content with data from the AmeriFlux research network, airborne sensors, and satellites. Biological process information from current experiments, atmospheric profiling, and statistical databases of the mid-continent region will play key roles. Results will help in the design of more comprehensive research for quantifying and explaining variation of carbon sources and sinks across North America.

- *Tracing Soil Carbon Fluxes* – Research will continue on a unique experiment using radiocarbon to trace carbon flux within soils. The results will improve models of soil carbon processes and quantification of belowground carbon sequestration.

These activities will address Questions 7.1 and 7.3 of the CCSP Strategic Plan.

Ocean Carbon and Climate Change Research. New studies will be initiated to advance the goals of the OCCC science implementation strategy:

- *Ocean Repeat Hydrography and Carbon Measurements* – The Repeat Hydrography Program will continue measurements of key ocean properties along cross-sections of the North Pacific. The suite of measurements will include total carbon, partial pressure of CO_2, temperature, depth, salinity, oxygen, and nutrients.
- *Coastal CO_2 Measurement Platforms* – Prototype platforms will be sited off the U.S. East Coast to continuously measure ocean CO_2 partial pressure and atmospheric CO_2 concentrations. The measurements will improve information on atmosphere-ocean CO_2 exchange and atmospheric CO_2 at the continental boundary.
- *Satellite Data Analysis* – New studies will focus on using ocean color to characterize carbon dynamics globally and on using a variety of satellite and *in situ* data to quantify and understand the spatial variability of air-sea CO_2 flux in the oceans adjacent to North America. Other studies will focus on the development and analysis of remote-sensing data and products that facilitate understanding of the input and fate of non-CO_2, climate-relevant carbon compounds (e.g., dissolved organic matter, CH_4, carbon monoxide) to the aquatic environment.



These activities will address Questions 7.1, 7.2, and 7.4 of the CCSP Strategic Plan.

Study of Terrestrial Processes Regulating Carbon Balance. Long-term field experiments and major campaigns are identifying processes that are critical to reducing uncertainties in carbon budgets and improving model-based predictions of future terrestrial carbon dynamics. A variety of experimental studies will be continued and several scientific syntheses are anticipated in FY 2006; new studies to better understand climate-related ecosystem effects on carbon balance will be conducted:

- *Productivity at FACE Sites* – Net primary productivity (NPP) is an integrated measure of how ecosystems respond to atmospheric CO_2 enrichment. Data from four forest ecosystems that are being exposed to elevated atmospheric CO_2 in FACE experiments will be analyzed and synthesized to determine how NPP is affected by elevated atmospheric CO_2 and other environmental factors.
- *Acclimation to Enriched Carbon Dioxide* – Results of two studies investigating acclimation (adaptation to a new environmental condition; in these cases, enriched atmospheric CO_2) processes will be published in 2006. These results are expected to underscore the importance of acclimation processes for ecosystem- to global-scale modeling of carbon cycling.
- *Amazonian Carbon Balance* – Integrative research utilizing data from the Large Scale Biosphere-Atmosphere Experiment in Amazonia will document current understanding of carbon source and sink dynamics, the processes controlling them, and any remaining uncertainties for the Amazon region of South America. These results are expected to greatly reduce errors and uncertainties concerning the carbon balance of tropical forests.
- *Impacts of Invasive Species* – Research on the impacts of invasive species on terrestrial carbon cycling processes will continue by studying the responses of different types of invasive species (grasses vs. woody species) along a precipitation gradient. The research will provide information about invasive species impacts on ecosystem productivity to make global estimates of carbon cycling more accurate and reliable.
- *Climate-Induced Permafrost Thawing and Associated Drying and Forest Fires* – Research will continue to investigate the relationship between water-table fluctuations and associated changes in soil carbon in northern latitudes of Alaska. Investigations of lake drying at Yukon Flats Wildlife Refuge will be initiated, and post-fire regrowth will be monitored at study sites established after the pervasive 2004 wildfires.

These activities will address Questions 7.1, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

Development of New Measurement and Analysis Methods. In FY 2006, the following work will be underway to develop new measurement and data analysis methodologies for carbon cycle science:

- *AmeriFlux Data Assimilation System* – An integrated framework for using AmeriFlux measurements and ecosystem models to understand terrestrial carbon cycling processes will be developed. This framework, which is called the AmeriFlux Data Assimilation System, takes advantage of diverse, continuous AmeriFlux measurements of CO_2 and energy exchanges and combines them with a detailed process-based ecosystem model. It will yield information on ecosystem states and carbon sinks in real time and will be an effective tool for scientists to investigate fundamental ecological processes that are difficult to observe directly.
- *New Remote-Sensing Measurements* – New remote-sensing research will be initiated to evaluate the technological capabilities for space-based measurement of: (1) vegetation three-dimensional structure and biomass; (2) phytoplankton and vegetation physiological properties and important plant functional types; and (3) the space-time variability of aquatic optical properties that may be translated into new ocean color observations of coastal particles and their abundance. All have direct relevance for quantifying global carbon sources and sinks.
- *Coastal Ocean Color Calibration* – Ocean color satellite calibration capabilities will be expanded to include observations of coastal zones. The objective will be to improve remote detection and quantification of optical, biological, and biogeochemical parameters in these regions. This research will improve our understanding of coastal biological and biogeochemical processes, improve coastal models, and eventually enable prediction of changes in processes such as offshore carbon fluxes.
- *Satellite Measurements of Atmospheric Carbon Dioxide* – Development of new remote-sensing capabilities for the measurement of atmospheric CO_2 will continue, and scientific research will be conducted to prepare for utilization of such data. Globally sampled measurements of atmospheric column CO_2 (i.e., column-integrated CO_2 dry air mole fraction) will increase by ~100 times the available measurements to drive inverse models and should enable regional resolution of carbon sources and sinks.

These activities will address Questions 7.1, 7.2, 7.4, and 7.5 of the CCSP Strategic Plan.

Improved Modeling for Projections of Carbon Dioxide and Climate. Continuing and new investments will be made in modeling studies to support NACP, the Mid-Continent NACP Intensive Campaign, the OCCC program, and activities on global carbon dynamics and climate change assessment.

- *Coupled Carbon-Climate Modeling* – Research will link terrestrial ecosystem models with climate simulation models to incorporate biogeochemical and physiological responses and feedbacks associated with climate change. Emphasis will be placed on

developing new code for including these ecosystem-scale processes and responses in current representations of coupled climate-land surface models. Priorities are to model an empirically derived respiration acclimation feedback to climate perturbation and to include physiologically based mechanisms of ecosystem response to CO_2 using FACE experimental data.

- *Carbon Data Assimilation* – Research will be conducted to develop, test, and apply carbon data assimilation and data fusion schemes that incorporate *in situ* and remotely sensed data and focus on enabling forecasts of changes in atmospheric CO_2 and CH_4 concentrations on short or long time scales with estimates of uncertainty. Studies to explore assimilation of coastal or ocean margin carbon data into general circulation models will be initiated.
- *Model Comparisons* – The southern Great Plains of the United States will be the focus for a model-based comparison of "bottom-up" and "top-down" approaches to estimating ecosystem CO_2 fluxes at the regional scale. Predicted temporally and spatially resolved gross and net CO_2 fluxes will be made available to NACP researchers to help evaluate NACP-related results for regional CO_2 exchange, climate, and land use.

These activities will address Questions 7.1, 7.2, 7.3, 7.4, and 7.5 of the CCSP Strategic Plan.

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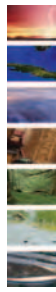


6 Ecosystems

Strategic Research Questions

8.1 What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?

8.2 What are the potential consequences of global change for ecological systems?

8.3. What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

See Chapter 8 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Ecosystems supply food, fiber, fuel, clean air and water, and many other goods and services to society. Global change is affecting the provision of these goods and services by altering ecosystems and biodiversity in complex ways. Observational and experimental studies reveal shifting ecosystem boundaries, changes in flowering or migration times, changes in ice breakup on streams and rivers, and changes in productivity and disturbance regimes (e.g., fires, pest and disease outbreaks). These observed changes might be associated with climate variability [e.g., El Niño Southern Oscillation (ENSO)], as well as other global changes such as gradual climate warming and fragmentation of ecosystem habitats.

The role of CCSP-supported ecosystems research is to increase the knowledge necessary to forecast the potential magnitude of global change effects on ecosystems and their feedbacks to the climate system, to help society respond effectively. In

FY 2006, research on ecosystems within CCSP will continue to focus on changes in ecosystems and the frequency and intensity of disturbances to ecosystem processes associated with global change, particularly those anticipated to have significant consequences for society during the next 50 years. This research will enable society to better protect both aquatic and terrestrial ecological resources and their goods and services.

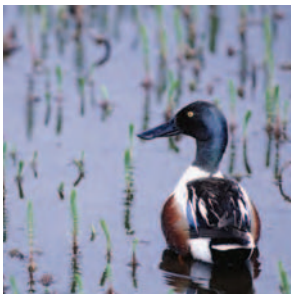
Successful research on the interactions of global change and ecosystems requires collaboration across agencies, as well as ongoing input from scientists within and outside the Federal Government to address scientifically important and socially relevant issues. To meet the goals of the ecosystems research element described in the *CCSP Strategic Plan*, the participating agencies work collaboratively on many research activities. Most of the research accomplishments and plans described in this chapter represent the joint efforts of multiple agencies. To engage the research community in providing input and feedback, the CCSP Ecosystems Interagency Working Group (EIWG) organized a workshop to bring together a broad array of scientists who were asked to identify and articulate priority research topics in support of the *CCSP Strategic Plan* for ecosystems research. Their report will be released in winter 2006 and will be an important reference as CCSP and participating agencies continue to develop science and implementation plans.

The ecosystems component of the FY 2006 CCSP budget request targets several high-priority research needs. One is improved measurements at multiple scales to better quantify and model ecological feedbacks to atmospheric chemistry and climate. Research is also being conducted to develop satellite tools that combine satellite observational data with physical and ecological models. These tools will improve our ability to understand and project changes in the distribution of organisms with changes in climate and other environmental factors. A number of projects on feedbacks between ecological systems and global change are closely related to feedbacks being investigated through other research elements. For example, carbon cycle feedbacks to warming, which are potentially quite significant, are handled largely by the global carbon cycle research element, but with input from the ecosystems research element. Land-surface biophysical feedbacks, which can be quantitatively significant in some modeling schemes, are handled through interactions with the land-use/land-cover change and the climate variability and change research elements. Related research in the ecosystems research element is being coordinated with these groups.

Aquatic ecosystem research priorities in FY 2006 include using integrated modeling systems, observations, and process studies to project the effects of climate variability and change on near-coastal and marine ecosystems, communities, and populations.

Research is also being conducted on the combined effects of changes in land use and climate on nonpoint sources of pollution entering estuaries. Estuaries are chosen because they are the natural integrators of upstream changes in land use and climate. The combined effects of other environmental factors on aquatic ecosystems are also being examined: studies of the effects of ultraviolet (UV) radiation and elevated carbon dioxide (CO_2) on freshwater planktonic lakes, shallow estuarine waters, and deeply mixed clear waters are being conducted using field work, observations, and ecosystem models.

Terrestrial ecosystems research priorities in FY 2006 include a long-term study of the western U.S. mountains and the relationship of observed sudden ecosystem changes to changes in climate conditions (e.g., reduction in the size of glaciers, changes in alpine treelines at their transition zone); the role of recent past, current, and future land-use change on carbon dynamics in eastern deciduous forests; and the effects of climate change on tree species population genetic structure to identify the genetic processes most critical to population survival and how they interact to affect species fitness. Long-term manipulative field experiments will be continued to better understand effects of warming, changes in precipitation, and changes in atmospheric composition on the functioning of forest, grassland, and shrubland ecosystems. A final priority topic is research on the effect of crop rotation, tillage, and nitrogen fertilization on the net global warming potential of agricultural systems, with the purpose of producing methods that may limit global warming potential in irrigated and rain-fed cropping systems while sustaining agricultural yields.



Highlights of Recent Activities

EIWG-Sponsored Workshop on Priority Setting for Ecosystems Research in CCSP. The EIWG sponsored a workshop, held in February 2004 in Silver Spring, Maryland, that brought together a diverse group of 70 scientists from U.S. universities, research centers and institutes, and Federal agency research programs in a "think tank" atmosphere for 3 days. The specific objective was to identify and articulate priorities and approaches for research under Chapter 8 of the *CCSP Strategic Plan*. Although the EIWG organized and funded it, the workshop was run by a steering committee from the science community. The workshop report is due in the winter of 2006 and will be available on the CCSP web site (see <www.usgcrp.gov/usgcrp/Library/ecosystems>).

Convergence in Ecosystem Water Balance over Continental Scales.[9] Water availability limits plant growth and production in almost all terrestrial ecosystems, but biomes differ substantially in sensitivity of aboveground plant growth, or aboveground

net primary production (NPP). A recent synthesis building on over 10 years of productivity data from 14 sites in North America showed that rainfall-use efficiency decreased across biomes as mean annual precipitation increased. However, during the driest years at each site, there was convergence to a common maximum value typical of arid ecosystems. In years when water was most limiting, deserts, grasslands, and forests all exhibited the same rate of biomass production per unit rainfall, despite differences in physiognomy and site-level differences in efficiency. Incorporating this information into ecosystem models will improve forecasts of future ecosystem behavior in the face of climate change.

Global Patterns in Human Appropriation of Net Primary Production.[10] Biophysical models were used in conjunction with data from the United Nations Food and Agriculture Organization to estimate the annual amount of Earth's terrestrial NPP or plant growth that humans require for food, fiber, and fuel using the same modeling architecture as satellite-supported NPP measurements. The amount of Earth's NPP required to support human activities is an aggregate measure of human impacts on the biosphere and an indicator of societal vulnerability to climate change. The amount of human-appropriated NPP (HANPP) for each country was calculated on a per capita basis for products consumed and then projected onto a global map of population to create a spatially explicit map of NPP-carbon "demand" (see Figure 20). The HANPP map was compared to a map of "supply" derived from Advanced Very High-Resolution Radiometer data from satellites. It was found that humans consume 20% of Earth's total NPP on land, with regional balances ranging from 6% consumed in South America to over 70% consumed in Europe and Asia, and local balances ranging from near 0% (central Australia) to over 30,000% for major urban areas (e.g., New York City). The uneven distribution of NPP supply and demand indicates the degree to which countries rely on NPP "imports" and suggests options for slowing future growth in NPP demand.

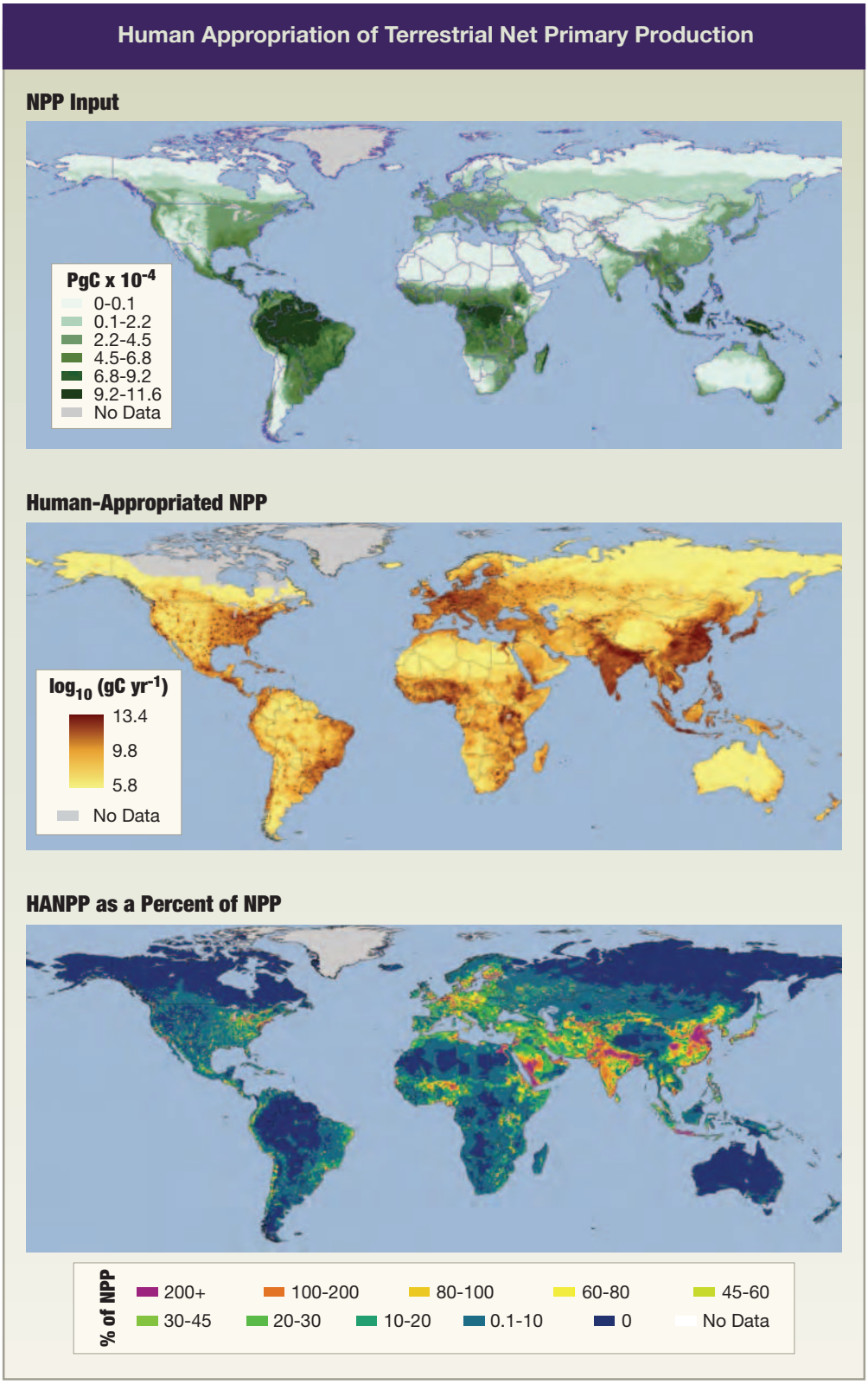


Figure 20: Human Appropriation of Net Primary Production on Land. Average annual terrestrial NPP (i.e., 'supply') based on 17 years of AVHRR satellite data (top); global distribution of human-appropriated NPP (HANPP, i.e., 'demand') for all food and fiber products (middle); and NPP-carbon balance (HANPP as a percent of NPP, calculated for each grid cell) (bottom). Highly populated areas (yellow and red) consume up to 300 times their local production. *Credit: M. Imhoff, NASA/Goddard Space Flight Center.*

Ocean Photosynthesis from Space.[1] The rate of photosynthesis for a given area is determined by its biomass of living plant material, the plants' growth rates, and the availability of sunlight. Until now, quantifying photosynthetic rates over large ocean areas has been difficult, if not impossible, because growth rates could not be characterized from space. The path to solving this problem is to use ocean color data analysis – specifically the application of partial wave analysis – that permits estimates of both the carbon biomass of ocean plants and their growth rates. This development will make it possible to use satellite remote sensing to improve estimates of ocean photosynthesis and detect changes over time.

Warming Interactions with Soil Carbon and Nitrogen in the Arctic Tundra.[12] Research results from the Arctic tundra in Alaska demonstrated how warming and consequent release of nutrients from increasingly decomposing soil organic matter will feed back positively and lead to increasing carbon losses from tundra soils. Data from a 20-year fertilization experiment showed that increased nutrient availability caused a net ecosystem loss of almost 2,000 gC m^{-2} (a 21% reduction over the 20-year period), even though annual aboveground plant production doubled, because of losses of carbon and nitrogen from deep soil layers. The results suggest that projected releases of soil nutrients associated with high-latitude warming may further amplify carbon release from soils, causing a net loss of ecosystem carbon and a positive feedback to climate warming.

Effects of Nitrogen Deposition on Water Quality and Carbon Sequestration.[16] Human effects on the natural cycling of nitrogen have caused significant alterations of land productivity, freshwater quality, and marine ecosystems. Nitrogen compounds generated by human activities are transported by the atmosphere and deposited onto ecosystems. Healthy forests remove much of the deposited nitrogen, storing it in plant tissues. In the Chesapeake Bay watershed, for example, forests retain 88% of deposited nitrogen, allowing only about 1 kg ha^{-1} yr^{-1} to leach into aquatic ecosystems (see Figure 21). As the level of deposition rises, the percentage of nitrogen retained declines and the amount of nitrogen released into downstream ecosystems increases. Nitrogen deposition will increase productivity in terrestrial ecosystems that are nitrogen deficient. Net carbon uptake by forests of the mid-Atlantic region could increase by 25% from nitrogen deposition; however, this rate of increase may be reduced by ground-level ozone pollution, which is damaging to many plant species.

Ecosystem Warming Facility Constructed and Operational. An ecosystem warming experimental facility was constructed in a boreal forest in northern Manitoba, Canada, and began operation during FY 2004. The facility exposes trees and soils to temperatures 5°C above ambient to examine potential effects of warming

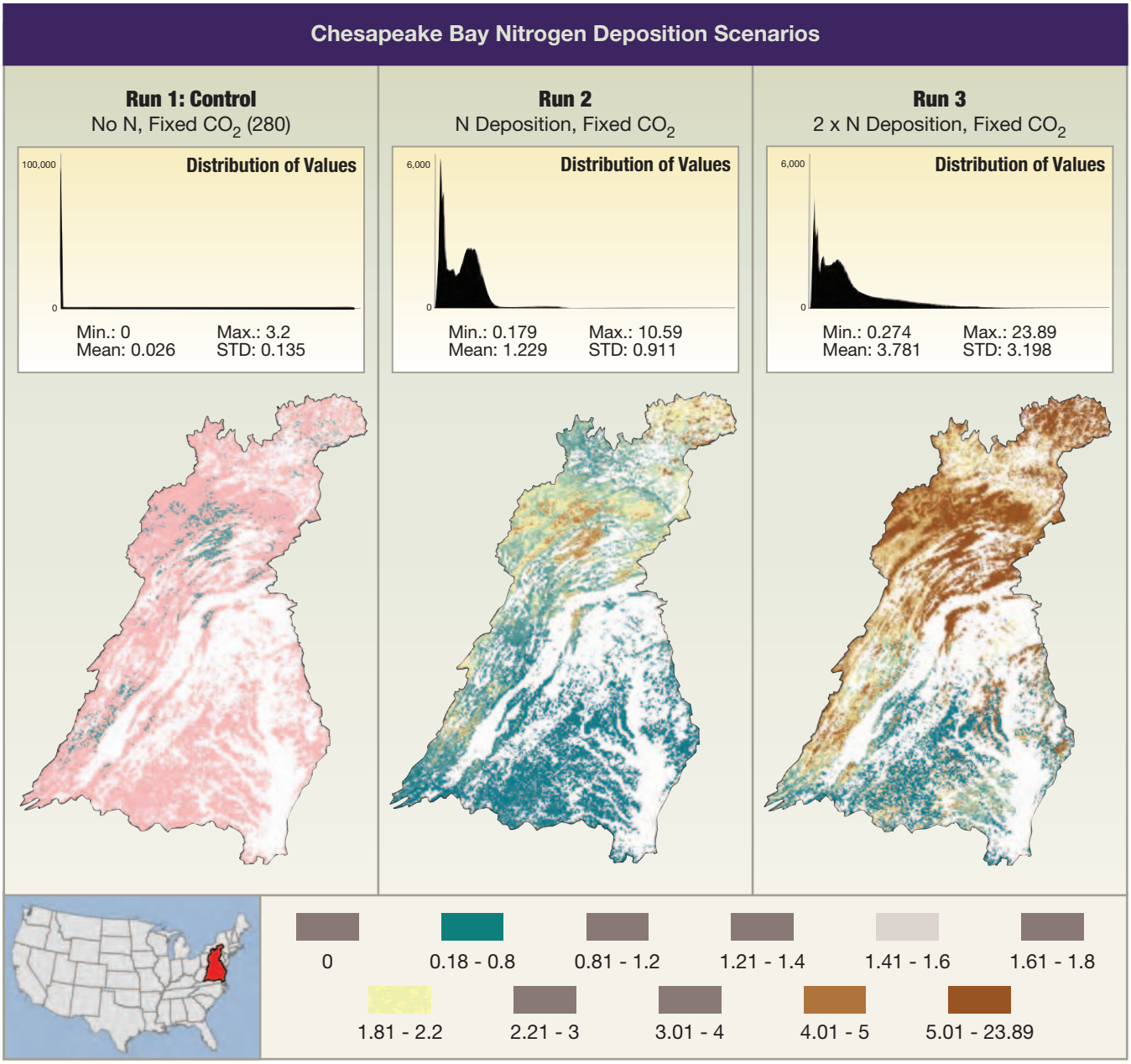


Figure 21: Chesapeake Bay Nitrogen Deposition Scenarios. Predicted losses of nitrogen from forested lands of the Chesapeake Bay watershed under no nitrogen deposition (left), current nitrogen deposition (middle), and doubled nitrogen deposition (right). *Credit: Pan* et al.*, 2004*.

on northern forests. Preliminary (FY 2004) data show acclimation of soil respiration to warming such that the rate of respiration (CO_2 release) following warming was about the same as the rate prior to warming, indicating a nearly complete acclimation to warming in the belowground component of the ecosystem. This result, if corroborated by continued data collection in FY 2005 and beyond, has important implications for

understanding a potential positive feedback on global warming caused by increased soil respiration in northern ecosystems (i.e., such a positive feedback might not occur in all ecosystems). In the warmed plots, tree growth began earlier in the spring and the growth of understory plants was greatly increased. Such changes in plant growth and its seasonal timing are important to the energy balance of northern ecosystems as the climate warms, and could result in a positive feedback to warming. Early results indicate greater carbon gains in the warmed plots relative to the ambient plots. For more information on this facility, see <per.ornl.gov/>.

Elevated Carbon Dioxide Effects on a Florida Ecosystem.[8] A study of a Florida scrub oak forest ecosystem suggested for the first time that the abundance of a trace element influenced the response of vegetation to elevated CO_2. The response of a nitrogen-fixing plant to elevated CO_2 declined over a 7-year period. The decline was strongly correlated to a decline in molybdenum, an element required for producing a key enzyme that affects nitrogen uptake by plants. The work illustrates that plant responses to elevated CO_2 may be highly species-specific. It also raises the possibility that the expected increase in plant growth due to elevated CO_2 could be limited by the availability of nitrogen.

Effects of Climate Change on Eastern U.S. Bird Species.[14] An atlas was produced that documents the current and potential future distribution of 150 common bird species in the eastern United States in relation to climate and vegetation distributions. Distribution data for individual species were derived from the Breeding Bird Survey from 1981 to 1990. Models were developed that related distributions of individual bird species to environmental variables (tree species abundance, climate variables, and elevation variables). Two scenarios of global climate change were then used to project potential changes in the distributions of the bird species. Depending on the global climate model used, as many as 78 bird species are projected to decrease by at least 25%, while as many as 33 species are projected to increase in abundance by at least 25% due to climate and habitat changes (see Figure 22 for an example).

Climatic Variability, Ecosystem Dynamics, and Disturbance in Mountain Protected Areas.[2,3,4,5,7,17,18] Northwestern mountain ecosystems play an important role in shaping the economies and landscape development of the region and provide services such as water purification and storage, and recreational opportunities. A project was initiated to quantify how the hydrological and ecological aspects of these ecosystems respond to climatic variability and large-scale landscape disturbance by examining past responses and projecting possible future outcomes of ongoing climatic change. The research project, Climate-Landscape Interactions on a Mountain Ecosystem Transect (CLIMET), was carried out across a transect of mountain systems

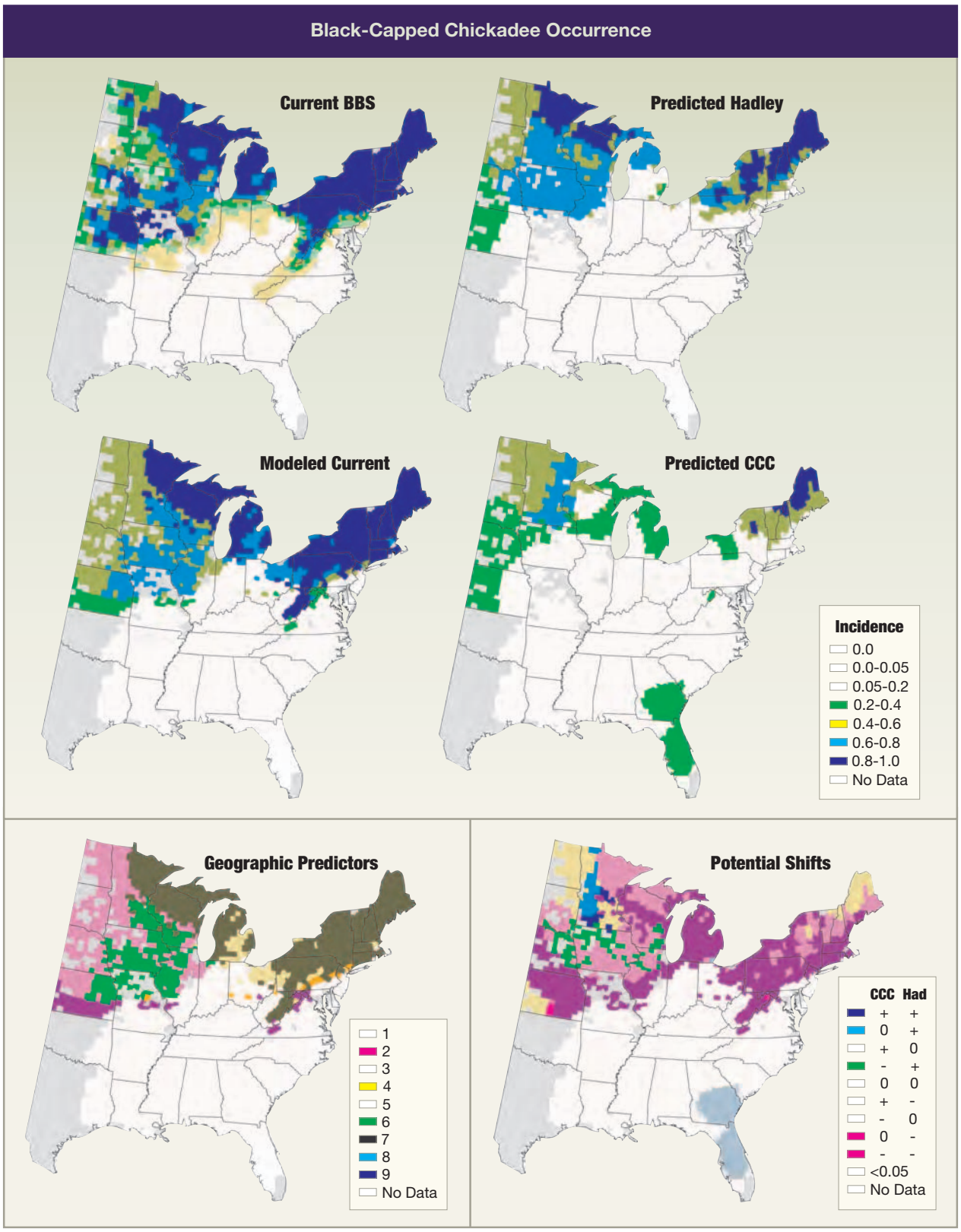


Figure 22: Black-Capped Chickadee Occurrence. Potential changes in occurrence of the Black-Capped Chickadee under two climate scenarios. "Incidence" refers to the proportion of sightings during annual breeding bird surveys. *Credit: Matthews* et al., *2004*.

along gradients of maritime to continental climate and decreasing landscape fragmentation (Olympic National Park, North Cascades National Park, and Glacier National Park) (Fagre and Peterson, 2002). The project has provided information on glacial decline, alpine forest changes, and ecological responses to climate variability (Fagre *et al.*, 2003). For example, an analysis of digital aerial photography and historical data documents that the number of glaciers in Glacier National Park has dropped from an estimated 150 in 1850 to 27 present today. The largest glaciers are, on average, only 28% of their previous size (see Figure 23). Future glacial recessions and vegetation distributions were projected using a geospatial modeling approach. Projections indicate that the largest glaciers will be gone in the northern Rocky Mountains by the year 2030 if current rates of warming continue (Hall and Fagre, 2003). The loss of glaciers in mountain watersheds will change the timing and amount of stream discharge and affect aquatic organisms dependent on cold waters.

Data are becoming available on the response of mountain ecosystems to climatic variability, particularly to multi-decadal trends in moisture. One such long-term pattern is the Pacific Decadal Oscillation (PDO), a period of above- or below-average sea surface temperatures in the Pacific Ocean that influences climate in the northwest part of North America. Mountain snowpacks in Glacier National Park track the PDO very closely and show regular 20- to 30-year periods of greater and lesser snow cover (Selkowitz *et al.*, 2002). These patterns explain glacier fluctuations and periods of increased tree growth in the northern Rocky Mountains (Pederson *et al.*, 2004). The frequency and size of forest fires in the Pacific Northwest also show a clear response to the PDO (Hessl *et al.*, 2003). Analysis of tree ring widths from drought-sensitive trees indicates that such multi-decadal oscillations have had an influence on these mountain environments for the past 500 years or more (Gedalof *et al.*, 2005). Such results suggest that it may be possible to forecast general mountain ecosystem responses to continuing climatic oscillations.

Sensitivity of Forests in Northern California to Climate and Fire Regime Variation.[19,21] Often, fire appears to serve as a catalyst for change during periods of rapid climate change. Time-series analyses show that vegetation associations with large, long-lived species (conifers) appear to lag in response to climate variations until major fires (as seen in charcoal influx to sediments) reset the stage and encourage major vegetation reorganization. This provides evidence of the potential influence of catastrophic fire on the reorganization of ecosystems under periods of rapid climate variation and could have major implications for habitat and forestry.

Leaf Pores: An Important Link among Increasing Greenhouse Gases, the Water Cycle, and Rising Temperatures.[13,15] Carbon dioxide and ozone (O_3), both greenhouse gases, directly affect plant physiological processes, including photosynthesis.

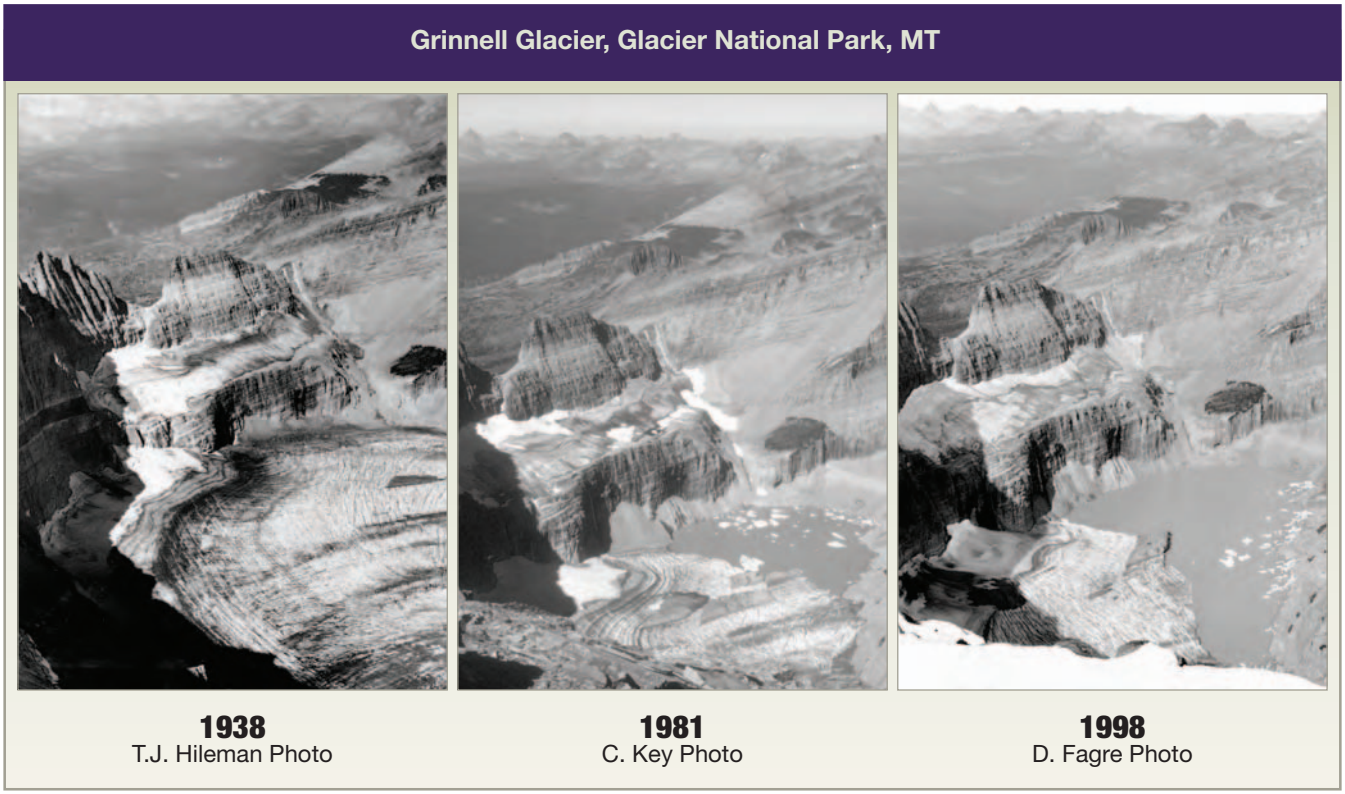


Figure 23: Glacier Retreat over the Past Century. Repeating photographs from the same location have provided visual documentation of the extent of glacier retreat over the past century. *Credit: USGS/Northern Rocky Mountain Science Center*.

These gases affect the opening and closing of microscopic pores (stomata) on plant leaves that regulate movement of water from the soil, through the plant, and into the atmosphere. Water vapor escaping through these pores cools the leaves and is important in the global water cycle. The number of stomata per unit of leaf area in grassland plant species in the southern United States was measured after the plants had been exposed for 4 years to a continuous CO_2 gradient spanning pre-industrial to near-double ambient concentrations. At higher CO_2 levels, stomatal density was greater for two species, decreased for one species, and unchanged for four species. In another field experiment using FACE technology, soybean plants were grown in the field at CO_2 and O_3 concentrations projected for the mid-21st century to explore how these changes in atmospheric composition might affect a nationally important agroecosystem. This work has provided the first field-scale evidence that rising CO_2 and O_3 concentrations decrease the loss of water vapor through the stomata and have the potential to substantially reduce summer moisture supply to the atmosphere (at the same time conserving soil moisture) and cause a warming of vegetated surfaces that will raise surface temperatures independently of greenhouse warming.

U.S. Marine Resource Managers Seek Guidance from Climate Scientists on Impacts of Regime Shifts.[11] Mounting evidence indicates that decadal climate changes in ocean productivity must be considered in assessments of fish stocks. In 1998, marine resource managers perceived a climate regime shift in the North Pacific. This shift resulted in cooler ocean conditions within the California Current System and Gulf of Alaska, but warmer surface waters in the central North Pacific. These changes apparently led to increased biological productivity within much of the California Current System and Gulf of Alaska (e.g., increased abundance of plankton and recruitment of many commercial fish stocks including Pacific salmon species, Pacific hake, and groundfish in the California Current System, and Pacific salmon species, shrimp, pollock, Pacific cod, and sablefish in the Gulf of Alaska), but decreased productivity in the Central North Pacific (e.g., northward shift in the low chlorophyll surface waters and decreased survival of monk seal pups in the northern atolls of the northwestern Hawaiian Islands). In response to this, the U.S. National Marine Fisheries Service requested advice from the North Pacific Marine Science Association on the potential effects of climate change on fish stocks in the North Pacific. An ad hoc group of U.S. and international scientists was formed, confirmed that the North Pacific entered a new climate state in 1998, and detailed the associated changes. The group advised agencies to develop management policies with explicit decision rules and subsequent actions to be taken when there are preliminary indications that a regime shift has occurred. Existing indicators, such as temperature and primary production, make it possible to detect shifts soon after they occur, but due to limited understanding of the mechanisms that lead to regime shifts, it is not possible to reliably predict how long any new state will last. The report included four recommendations for incorporating regime shift concepts into fishery management activities: accept the regime concept for marine ecosystems; develop and maintain a comprehensive observational program to monitor changes; develop climate indices to aid ecosystem monitoring efforts; and make use of fish stock assessments to evaluate the vulnerability of ecosystems to various future regime scenarios.

New Long-Term Ecological Research Network Sites in Coastal Areas. The addition of the Moorea Coral Reef and the California Current Ecosystem to the Long-Term Ecological Research (LTER) Network has expanded the number of LTER sites to 26. These two new sites significantly augment the LTER Network, which had previously included only one marine site in the Antarctic, and ensure that high biodiversity and productivity ecosystems in most of the world's major biomes are represented in the network. Understanding gained from the site on the island of Moorea in the South Pacific will enable more accurate projections of how coral reef ecosystems respond to environmental change, whether human-induced or from natural cycles. The California Current System sustains active fisheries for a variety of finfish and shellfish, modulates

weather patterns and the hydrologic cycle of much of the western United States, and plays a vital role in the economy of myriad coastal communities. Research will focus on how the influences of El Niño, the PDO, and multi-decadal warming trends affect these systems. The LTER program continues to have a major network-wide focus on climate change impacts on ecosystems (see <www.lternet.edu>).

Coral Reef Watch: Satellite Input.[6,20] The number of reported coral reef bleaching events was minimal before the ENSO events of 1998 and 2002. During these events, significant coral mortality occurred throughout western Pacific and Caribbean coral reefs, bringing to light one likely correlation between anomalous temperatures and ecosystem response (Urban *et al.*, 2000). Since then, scientists have been developing an understanding of the potential causes and links leading to significant coral bleaching events. The Coral Reef Watch Program (see <coralreefwatch.noaa.gov>) uses land- and satellite-based instruments and *in situ* tools for near-real-time and long-term monitoring, modeling, and reporting of physical environmental conditions of coral reef ecosystems. Biological, physical, and environmental data critical to coral reef ecosystems are continuously received, input into Coral Reef Watch, and provided to Reefbase (see <www.reefbase.org>), a global information system. These data are used to help design future marine protected areas, coral reef parks and refuges, and research areas (Heron and Skirving, 2004). Linking ecosystem models with current and past climate data will enable scientists to understand the relationship between climate parameters and coral ecosystem response. These efforts will provide tools that managers and stakeholders can use in the field to conserve corals. It is important to continue the acquisition of Landsat-like satellite data for these purposes.

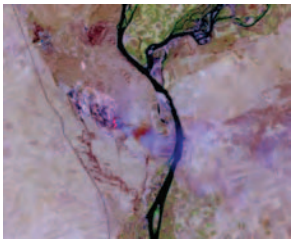
Creation of the National Ecological Observatory Network. Work was initiated with the American Institute for Biological Sciences to set up a National Ecological Observatory Network (NEON) Design Consortium and Project Office. This consortium will develop a blueprint for the network and a plan for its implementation. NEON will be the first national observation system designed to answer ecological questions at regional and continental scales. Data from the network will help to develop a predictive understanding of the relationship between environmental change and biological processes. Focus areas for NEON include the impact of climate change on forests and agriculture, the emergence and spread of infectious diseases, the causes and consequences of invasive species, and the forecasting of biological change. For more information, see <www.neoninc.org>.

Highlights of FY 2006 Plans

Definition of Requirements for Ecosystem Observations. An ongoing analysis of existing data, model projections, and conceptual hypotheses is expected to be completed during FY 2006. The analysis will draw on output from workshops, reviews of existing scientific literature, and new model calculations to provide an initial definition of the requirements for ecosystem observations needed to quantify ecological feedbacks to climate and atmospheric composition. The specification of requirements will seek to enhance the use of existing observing systems, but will also consider needs for new observing capabilities. The activities to be completed during FY 2006 will focus on the western United States, but are expected to provide a solid scientific base for similar activities for other regions.

These activities will address Question 8.1 of the CCSP Strategic Plan.

Use of Remote Sensing to Detect and Forecast Global Change Effects. By combining satellite observation data with physical and ecological models, progress is being made toward the goal of using remote sensing to relate changes in climate and other environmental factors to changes in the distributions of organisms and how they relate to their environments. The groundwork is being laid for improved satellite-based tools for detection of changes in marine and terrestrial plant physiology as well as for distinguishing between groups of organisms having different roles in the cycling of elements and water. Improvements in our ability to remotely sense the three-dimensional structure of habitats also help to meet the goal. Coupling observationally driven models across spatial scales and model types (e.g., linking regional climate models to ecosystems food web models) is providing a better understanding of the connections between the geophysical and biological components of this planet. In one example planned for FY 2006, integrating global climate models and regional climate models with food web models will result in forecasts of the impacts of interannual climate phenomena, such as ENSO events, on the productivity of specific fisheries. These forecasts should promote more sustainable harvests of fish stocks.



These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Models and Indices for Improved Fisheries Management. The ongoing North Pacific Climate Regimes and Ecosystem Productivity project will integrate observations and understanding into predictive models, metrics, and indices of ecosystem status and trends for use in marine fisheries management. Expanded monitoring will increase our understanding of how climate influences the structure and function of ecosystems in the eastern Bering Sea and northern Gulf of Alaska. Central components of the monitoring system are regional biophysical moorings and research cruises. Analyses of data from the monitoring system will be used to construct

and validate new conceptual and predictive models and to provide indices of ecosystem status. These results will provide resource managers with knowledge and tools to adapt to the consequences of climate change for marine ecosystems.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Determining the Effects of Climate Variability on Marine Populations. U.S. GLOBEC (Global Ocean Ecosystems Dynamics) is a research program organized to address the question of how global climate change may affect the abundance and production of animals in the sea. It has supported major field research efforts in the Georges Bank/Northwest Atlantic Region, the Northeast Pacific, and the Southern Ocean and western Antarctic Peninsula. These field studies have incorporated observations of physical and biological oceanographic parameters in the three regions, process studies to understand mechanisms and dynamics driving these ocean ecosystems, and modeling developments to link physical and ecological processes in a predictive framework. In FY 2006, researchers will begin synthesizing results to provide increased overall understanding of the responses of these ecosystems to climate variability, and allow predictions of population responses. The U.S. GLOBEC program will also provide advice to guide ecosystem-based management of marine resources in the face of climate change.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Elevation Maps Depicting Areas Vulnerable to Sea-Level Rise and Planning Maps Depicting How State and Local Governments Plan to Respond to Sea-Level Rise. A tool using sea-level rise elevation and planning maps is being designed for coastal planners at all levels for use in developing master plans. It will provide high-precision maps that will delineate low-lying lands that would be eroded or inundated as the sea rises. Along with overlying maps of planned or existing infrastructure, habitat types, and models of ecosystem response to inundation, this will provide managers of coastal development with sufficiently detailed information to accommodate expected consequences of sea-level rise. The ongoing effort will provide this product for part of the coast of North Carolina and be a template for future work along other low-lying coasts.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Effects of Ultraviolet Radiation and Elevated Carbon Dioxide on Aquatic Ecosystems. Ongoing research is being conducted on UV radiation effects in a variety of aquatic ecosystems including freshwater planktonic lakes, shallow estuarine waters of the Chesapeake Bay, and deeply mixed, clear waters of the Ross Sea, all of which can be exposed to enhanced UV-B radiation. The responses of key flux processes (e.g., carbon and nitrogen cycling) to UV radiation are being measured and used to develop

ecosystem models that include UV as a factor. The models also include the effects of elevated CO_2 on the production of UV-absorbing carbon compounds in adjacent marsh ecosystems, which are the subject of an ongoing field manipulation.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Linkages between Tropical Storms, Ecosystem Diversity, and Climate Change in Pacific Islands. A research project will examine the effects of a particularly severe typhoon (Sudal) on upland forests, mangroves, and seagrass ecosystems in Micronesia. This typhoon resulted in the deposition of large quantities of wood (fuels) on the forest floor and increased susceptibility to severe wildfire. Shifts in invertebrates of seagrass and mangrove ecosystems, forest structure, and the composition and recovery of the marine and mangrove biota will be measured and compared to similar ecosystems unaffected by recent typhoons on neighboring islands. Observations will continue through 2006. The results will improve information for planning adaptation measures for Pacific Island forest and marine ecosystems and societies to the potential for more severe or frequent tropical cyclones or increases in the occurrence of El Niño events.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Understanding Ongoing Changes in the Mountains of the Western United States. A study was launched by the USGS Fort Collins Science Center, Northern Rocky Mountain Science Center, Western Ecological Science Center, and the USDA Forest Service Pacific Northwest Research Station to better understand ongoing changes in the mountains of the western United States. Aims of the study include understanding the causes of sudden changes in mountainous areas, such as the recent die-off of trees on millions of acres in New Mexico, Arizona, and southern California. Since 2002 in the Jemez Mountains, mortality of overstory piñon has exceeded 95% (by spring 2004), and most piñon seedlings have died. Local piñon-juniper woodlands are being rapidly and massively transformed in the southwestern United States by the current combination of warm and dry climate conditions. These results highlight the potential for rapid, drought-induced changes in woody vegetation due to extreme climate events.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Final Data Collection from the Longest Large-Scale Ecological Climate Change Experiment. The Throughfall Displacement Experiment located in a deciduous hardwood forest in eastern Tennessee has been studying whole-forest responses to altered precipitation, a possible component of climatic change, continuously since 1993. The project has provided much new and unique data during its lifetime, some of which was summarized in a 2003 book devoted to the experiment. This experiment has also served as an important source of data for the development and testing of a wide range of ecosystem models. During FY 2006, final data collection will occur for this large-scale field experiment. The precipitation manipulations will be ended and extensive characterization of the effects of 13 years of chronic changes in the precipitation inputs to the forest ecosystem will be completed.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Polar Bear Survival in a Vanishing Sea-Ice Environment. The polar bear (*Ursus maritimus*) is the top predator of the Arctic marine ecosystem. Throughout their range, they are dependent on sea ice for nearly all aspects of their life history. Evidence indicates that Arctic regions have warmed recently, and that one of the most prominent effects of these changes is an altered sea-ice environment. Hence, polar bears, which may be the first large mammal to show obvious effects of climate change, are an ideal "indicator" of the status of the Arctic system. This study will examine how sea-ice quality and condition have changed and will change for the period between 1985 and 2008. It will establish how polar bears adapt to those changes

spatially, and will test whether there is evidence that spatial responses, mediated by climate change, alter polar bear condition, productivity, and survival of young.

These activities will address Question 8.2 of the CCSP Strategic Plan.

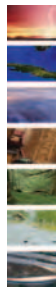
Dynamics of Historic Species Ranges and Implications for Conservation. The effects of climate change on tree species population genetic structure are being quantified. The research approach is primarily through natural experiments; for example, species whose ranges were fragmented by past environmental change, largely the global warming that ended the last glacial period and the Holocene climatic fluctuations that followed. Measures of population structure and health, including genetic diversity, rates of gene flow, and inbreeding, are estimated from molecular markers for threatened and fragmented populations. The goals of the research are to identify the genetic processes most critical to population survival and how they interact to affect species fitness. The findings will be used to recommend management strategies to help provide species and gene conservation. Data collection and analysis will continue in FY 2006.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Effects of Changes in Land Use and Climate on Non-Point Source Pollution in Estuaries. Climate and land-use change will affect the constituents of non-point source pollution entering water bodies. Non-point sources of pollution come from agriculture, suburban, and urban land uses. Changes in precipitation, for example, combined with changes in these land uses, will affect the ratio of nutrients and pollutants entering water bodies. Estuaries are natural integrators of upstream changes in land use and climate and are therefore the focus of research to be initiated in FY 2006. Selected locations with water quality monitoring and land-use data will be used to model the effects of climate and land-use changes on ecological endpoints. Best management practices scenarios and the relevant ecological endpoints will be identified through stakeholder workshops. Based on workshop results, analyses will explore management options to estimate their effectiveness at reducing projected impacts on water quality and valued ecological endpoints.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Climate Change Effects on Bioindicators and Biocriteria Programs. Biocriteria are narrative descriptions or numerical values (e.g., community composition, abundance of specific "indicator" species) that are used to describe the condition of a water body that supports aquatic life. Biocriteria help to identify cumulative effects of all stressors within a water body. These ecological indicators may be vulnerable to changes in temperature, stream flow, sedimentation, the timing, amount, and seasonality of precipitation, and land-use changes. Biocriteria programs are designed to compare



reference sites with non-reference sites to detect impairment. However, the combination of climate change and land-use change effects on biocriteria may cause baseline conditions at reference and non-reference sites to change, making impairment difficult to interpret. In FY 2006, case studies will be initiated in several States and for several aquatic ecosystems to identify those biocriteria metrics that are sensitive to climate and land-use changes, and those bioindicators that may be used to monitor shifting baselines between reference and non-reference sites. These studies will outline the general implications of climate change and land-use change for aquatic ecosystem health and for biocriteria programs.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Effect of Agricultural Practices on Net Global Warming Potential. Research will provide new information about the effect of crop rotations, tillage, and nitrogen fertilization on the net global warming potential of agricultural systems – that is, the difference between total greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide) and carbon sequestration. Collection of emissions and sequestration data along with soil environmental factors related to trace gas exchange will assist in verification of simulation models that can be used to estimate net global warming potential on larger spatial and temporal scales. In FY 2006, these analyses will lead to the development of methods by which global warming potential can be limited in irrigated and rain-fed cropping systems while sustaining agricultural yields.

These activities will address Question 8.3 of the CCSP Strategic Plan.

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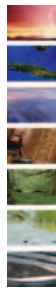


7 Decision-Support Resources Development and Related Research on Human Contributions and Responses

CCSP Decision-Support Goals

Decision-Support Goal 1: Prepare scientific syntheses and assessments to support informed discussion of climate variability and change and associated issues by decisionmakers, stakeholders, the media, and the general public.

Decision-Support Goal 2: Develop resources to support adaptive management and planning for responding to climate variability and climate change, and transition these resources from research to operational application.

Decision-Support Goal 3: Develop and evaluate methods (scenario evaluations, integrated analyses, and alternative analytical approaches) to support climate change policymaking and demonstrate these methods with case studies.

Strategic Research Questions

9.1 What are the magnitudes, interrelationships, and significance of the primary human drivers of, and their potential impact on, global environmental change?

9.2 What are the current and potential future impacts of global environmental variability and change on human welfare, what factors influence the capacity of human societies to respond to change, and how can resilience be increased and vulnerability reduced?

9.3 How can the methods and capabilities for societal decisionmaking under conditions of complexity and uncertainty about global environmental variability and change be enhanced?

9.4 What are the potential human health effects of global environmental change, and what climate, socioeconomic, and environmental information is needed to assess the cumulative risk to health from these effects?

See Chapter 11 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of decision-support resources development and Chapter 9 for these specific research questions.

Decisionmakers, resource managers, and other interested citizens need reliable science-based information to make informed judgments regarding policy and to take relevant action to address the risks and opportunities of changes in climate and related systems. Providing this information is the overall purpose of CCSP. This calls upon research-based resources distributed throughout the program's research elements and CCSP's 13 participating departments and agencies. A specialized element of CCSP research described in this chapter focuses on development of resources to support decisionmaking and related research on human contributions and responses to environmental change.

Decision-Support Resources

Decision-support resources include analyses and assessments, interdisciplinary research, analytical methods (including scenarios and alternative analysis methodologies), model and data product development, communication, and operational services that provide timely and useful information to address questions confronting policymakers, resource managers, and other stakeholders. This research is especially relevant to CCSP Goal 5: "Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change."

Development of decision-support resources is targeted at three broad categories of uses: (1) input to discussions of climate variability and change by decisionmakers, stakeholders, the media, and the general public; (2) adaptive management and planning; and (3) policy decisions. Each of these categories has a unique set of stakeholders and requires different decision-support tools. However, they share a common reliance on partnerships between scientists and stakeholders to define the problems to be addressed, the nature of decision-support resources to be developed, the expected information to be provided, and the approach for describing levels of confidence and key uncertainties (see the chapter banner for more detail on the goals of decision-support resources development).

Expected outcomes of those CCSP activities focused on the development of decision-support resources include:

- Improved science syntheses and assessments for informing public discussion of climate change issues
- Expanded adaptive management capacity to facilitate the responses of resource managers to climate variability and change
- Assessment information for evaluating options for mitigation of and adaptation to climate variability and change
- Identification of information needs to guide the evolution of the CCSP science agenda.

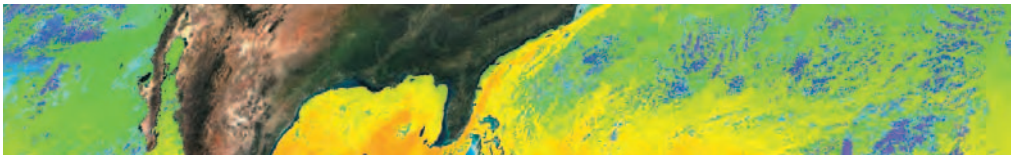
CCSP is encouraging research (described in this chapter) to improve existing assessment methods and to develop new approaches that integrate research from the physical, chemical, biological, medical, engineering, and social sciences. According to the National Research Council (NRC), "In order to address the consequences of climate change and better serve the Nation's decisionmakers, the research enterprise dealing with environmental change and societal interactions must be enhanced." Such an enterprise should include "…support of interdisciplinary research that couples physical, chemical, biological, and human systems" (NRC, 2001).

Related Research on Human Contributions and Responses to Environment Change

Successful development of decision-support resources requires a research base that includes not only research in the natural sciences but that also focuses on human contributions and responses (HCR) to changes in climate and related systems – sometimes known as "human dimensions" research. This research covers a number of questions and is a key – but certainly not the only – part of the foundation for improved decision-support resources, and is also discussed in this chapter (see the chapter banner for more detail on key HCR research questions). HCR research includes studies of the interactions of environmental change with a number of aspects of human systems, including:

- Demography (population evolution and change)
- Economics (e.g., national economic growth, international trade, technology development and diffusion, and economic implications of potential impacts and adaptation or mitigation measures)
- History and anthropology (e.g., response of societies to past environmental changes)
- Political science and sociology (e.g., organizations and their role in the policy process; institutions and their role in shaping decisions and behavior).

This research adds to an understanding of how humans contribute to changes in the global environment, why some societies are more resilient and others are more vulnerable to change, and how attributes of social and economic organization can make it either easier or more difficult to mitigate and to adapt to global environmental change.

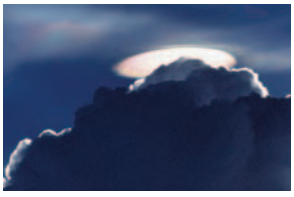


Coordinating Decision-Support and Human Dimensions Research

For the first time, this edition of *Our Changing Planet* combines "Decision-Support Resources Development" and "Human Contributions and Responses to Environmental Change" in a single chapter. This reflects the NRC's recommendation to enhance research on the *connections between environmental change and societal interactions to better support decisionmaking*. It also reflects a commitment on the part of CCSP to improve the interactions between development of decision-support resources and human dimensions research. Improving coordination between decision-support resources development and research on human contributions and responses will be advantageous because both areas share a number of challenges. Both areas require a systematic approach to examining how decisionmakers use information about climate and the environment in decisionmaking. And both depend on the integration of social, economic, and health data with environmental data. Such integration requires that information from diverse disciplines be available at compatible temporal and spatial scales. Geo-referenced data are needed to support investigation of the interactions of environmental and socioeconomic trends in specific places and decision contexts.

There is a risk that treating these topics together will mistakenly imply that decision-support resources development depends solely on this specific area of research, or that the study of human contributions and responses to change is limited to only supporting decisions. Neither statement is correct. Development of decision-support resources cannot be isolated in a single program element, disconnected from research throughout CCSP. Responsibility for developing decision-support resources is distributed across CCSP and success depends on developing strategies for integrating knowledge from the many diverse fields represented in the program. CCSP's strategy for improving understanding of human-environment interactions recognizes the need for basic research into the human dimensions of global change that may not lead directly to decision-support resources. This chapter describes both sets of activities and begins to explore their interrelationships.

Decision-Support Resources Goal 1: Scientific Syntheses and Assessments



The Global Change Research Act of 1990 (P.L. 101-606, section 106) directs the USGCRP to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic science "assessments." The *CCSP Strategic Plan*

defines "assessments" as "processes that involve analyzing and evaluating the state of scientific knowledge (and the associated degree of scientific certainty) and, in interaction with users, developing information applicable to a particular set of issues or decisions." Assessments are an effective means for integrating and analyzing CCSP research results with other knowledge, and communicating useful insights in support of a variety of applications for decision support. Assessments also help identify knowledge gaps and thus provide valuable input to the process of focusing research.

The synthesis and assessment products are special cross-cutting products focused on and relevant to a number of science and policy issues (see sidebar for an example). The synthesis and assessment products being generated by CCSP fall under this mandate and focus on a variety of science and policy issues important for public discussion and decisionmaking. CCSP agencies will carry out the analyses with interagency cooperation to ensure the best utilization of resources from the entire program. This approach will cover the full range of CCSP goals and will provide a "snapshot" of knowledge concerning the environmental and socioeconomic aspects of climate variability and change. The 21 synthesis and assessment products are listed in Table 2-1 of the *CCSP Strategic Plan*, aligned with the CCSP goals they address. The scope of a few of these (i.e., 4.3, 4.5, 4.6, and 4.7) has been modified from those listed in the *CCSP Strategic Plan* to make the suite of products more responsive to Section 106 of the Global Change Research Act.

To facilitate preparation of the products, CCSP published a set of guidelines that define a methodology that includes development of a prospectus with open scientific and public comment, reliance on scientific experts to draft the products, scientific peer review followed by open public comment on the drafts, and approval for publication

SYNTHESIS AND ASSESSMENT PRODUCT 5.2

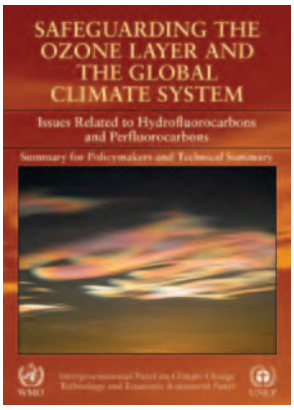
Best-Practice Approaches to Characterize, Communicate, and Incorporate Scientific Uncertainty in Decisionmaking. Synthesis and Assessment Product 5.2 will address the issue of uncertainty and its relationship to science, assessment, and decisionmaking. Specifically, the product has the following purposes:

1) Improve the quality and consistency of information about scientific uncertainty presented to decisionmakers and other users of CCSP's reports by identifying "best practice" options recommended in the literature on this subject
2) Improve communication between scientists and users of the products by providing a simple guide to interpreting information about uncertainty contained in the reports
3) Provide a brief overview of the literature on approaches for taking account of uncertainty in decisionmaking.

The report's "best practice" guidelines will be tailored for different types of products so that the treatment of uncertainty in CCSP products is more systematic and helpful to users. A team of leading experts in decision and risk analysis will draft the report, supported through NSF. Representatives of participating CCSP agencies will work with the authors to ensure that the technical advice developed is useful and appropriate for the CCSP process.

by the interagency governing body of CCSP, including a role for the NRC to provide additional analysis and to bound uncertainty. These guidelines are described more completely in the overview chapter of this report, and are available in their entirety on the CCSP web site (see <www.climatescience.gov/Library/sap/sap-guidelines.htm>.

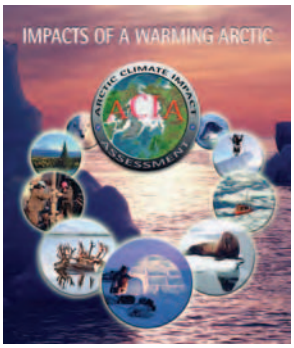
CCSP agencies and scientists funded by these agencies will continue to participate in international science assessments, including the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report* scheduled for completion in 2007, the Arctic Climate Impact Assessment, the Millennium Ecosystem Assessment, the International Research Institute for Climate Prediction, and the World Meteorological Organization/ United Nations Environment Programme assessments of stratospheric ozone depletion and associated environmental impacts.



The United States supports these assessments in a variety of ways. For example, the U.S. Government has played an active role in the IPCC process since its inception in 1988. It continues to support the IPCC actively. The United States chairs IPCC's Working Group I (which focuses on the climate system) and provides support for its Technical Support Unit. Working Group I played a lead role in the *Special Report on Safeguarding the Ozone Layer and the Global Climate System* (completed in July 2005, see <www.ipcc.ch/pub/reports.htm>) and is currently leading development of the science volume of the *Fourth Assessment Report* (AR4).

Through participation in the IPCC process, the U.S. Government helps guide development of an important set of international assessments – including the reports mentioned above, the impacts and response option volumes of the AR4, and a Working Group III Special Report on Carbon Capture and Storage. CCSP supports participation of experts to serve as Coordinating Lead Authors, Lead Authors, and Review Editors of the reports and to participate in workshops that contribute to the process. At present, 116 U.S. scientists serve as authors of the five reports under preparation, and 15 as Review Editors. CCSP also coordinates the U.S. reviews of draft reports at the request of the Department of State. Further information on the IPCC can be obtained at <www.ipcc.ch>.

CCSP-supported scientists also participated in the Arctic Climate Impact Assessment (ACIA), which focused on potential impacts of climate variability and change, ozone depletion, and other interacting environmental changes on a broad range of Arctic ecosystems, socioeconomic conditions, and natural resources. ACIA officially started in October 2000 and was completed during fall 2004. The Arctic Council, including its Senior Arctic Officials, provided oversight through progress reports and documentation at Arctic Council meetings. Funding was provided to ACIA through both direct and



indirect support from each of the eight Arctic nations. As the lead country for ACIA, the United States provided financial support through NSF and NOAA, which allowed the establishment of an ACIA Secretariat at the University of Alaska, Fairbanks. Contributions from the other Arctic countries, as well as from the United Kingdom, supported the involvement of their citizens and provided in-kind support, such as hosting meetings and workshops. Further information on ACIA is available at <www.acia.uaf.edu>.

Related HCR Research on Assessment and Decision-Support Methods

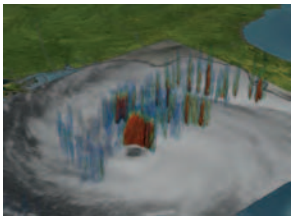
CCSP is encouraging research to improve methods of assessment and decisionmaking under uncertainty. This research examines a number of key issues including: designing processes for assessment that effectively focus scientific analyses on decisionmaking issues; more effectively encouraging public participation in assessments; estimating the costs and opportunities (market and non-market) of environmental changes; improving approaches for representing, analyzing, describing, and communicating uncertainty in assessments; and improving understanding of climate-change related decisions under uncertainty.

One example of this area of research is a project conducted by researchers at Harvard University that seeks to understand and promote the design of effective systems to harness research-based knowledge in support of decisions related to human development and environmental stewardship. The project has found that decision-support systems are likely to be more effective to the extent that they cultivate and protect "bridging" or "boundary" organizations that actively promote two-way connections and dialog between the research and applications communities (RASSP, 2003; NRC, 2005).

Highlights of Plans for FY 2006

Decision Making Under Uncertainty Program. Under its Decision Making Under Uncertainty (DMUU) program, NSF initiated grants for five interdisciplinary university and private sector research teams to study important aspects of problems associated with understanding climate-related decisions under uncertainty. These teams are expected to produce new insights of interest to the academic community, generate significant educational benefits, and develop new tools that will benefit policymakers, decisionmakers, and different stakeholders. In FY 2006, the DMUU research teams will conduct integrative research on scales larger than normally would be expected through individual research projects. In addition to conducting fundamental research, the teams will develop tools that people, organizations, and governments can use to better understand the risks associated with climate variability and change and the

options they have to address those risks; provide education and research opportunities for U.S. students and faculty; and develop and disseminate tangible products for researchers, decisionmakers, and other relevant stakeholders.



DMUU publications are planned for FY 2006 that will disseminate the outcomes of a set of workshops conducted by economists examining the adequacy of the representation of climate change uncertainties and the development of decision criteria and analytical tools for decisionmaking in the face of these uncertainties. They will place particular emphasis on the formulation of climate change adaptation and mitigation response options. Also appearing in FY 2006 will be publications and web-based products resulting from a series of workshops and seminars that bring together researchers and practitioners for extended examination of especially promising topics that bridge climate change and decisionmaking research and analysis, including alternative methods for uncertainty-based analysis of climate change impacts, vulnerability, and adaptation; analysis of greenhouse-gas emission projections and mitigation policies under uncertainty; and the applicability and limits of the "insurance" analogy for responding to the threat of global climate change.

This research contributes to CCSP Strategic Plan Question 9.1, Goals 11.2 and 11.3, and Synthesis and Assessment Product 5.2.

Evaluating Case Studies of Knowledge for Decisionmaking. The Knowledge Systems project at Harvard University will synthesize insights emerging from case studies through a series of papers addressing the principal challenges of governance and financial arrangements; linking knowledge with decisionmaking; and facilitating adaptive learning. A three-part special issue will be published by the *Proceedings of the National Academies* with case studies and guidelines for designing effective systems to harness research-based knowledge in support of decisions bearing on the joint goals of human development and environmental stewardship. Findings of the Knowledge Systems project are being extended and evaluated through a series of workshops run in collaboration with the National Academies' Roundtable on Science and Technology for Sustainability, co-chaired by NOAA Deputy Administrator James Mahoney and Stanford University Dean Pamela Matson and engaging high-level decisionmakers from business, government, and civil society.

This research contributes to CCSP Strategic Plan Question 9.1 and Goal 11.2.

Learning from Climate Assessment. In partial fulfillment of CCSP's commitment to build on the "lessons learned" from earlier assessment activities, CCSP has requested that the NRC carry out an analysis of global change assessments that have addressed topics broadly similar to those encompassed by CCSP. This study will examine which assessment approaches (in terms of geographic scale, scope, assessment entity, and timing) and products are most effective for meeting CCSP's stated objectives for

assessments, as outlined in Chapter 11 of the *CCSP Strategic Plan*. The study is described in greater detail in the introduction to this report.

This project contributes to CCSP Strategic Plan Goal 11.1.

Decision-Support Resources Goal 2: Adaptive Management/Planning Decisions

"Adaptive management decisions" are operational decisions, principally for managing infrastructure (e.g., wastewater treatment systems), natural resources (e.g., a watershed), or societal response mechanisms (e.g., health alerts). They occur within existing legal and institutional frameworks, usually recurring on annual (or shorter) time scales. "Planning" focuses on these and additional sectors (e.g., urban or regional planning), typically involving development of infrastructure and institutions with long lifetimes (several decades or more), and with decision processes over long time scales (years to decades). CCSP has adopted a distributed approach to developing these decision-support resources that draws on ongoing activities in contributing departments and agencies in many sectors and settings.

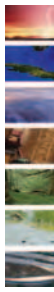
CCSP research results, data products, forecasts, and model results are already being applied to adaptive management and planning in a number of regional and sectoral case studies. Specific examples include climate observations and projections for crop management, water quality management, and urban planning, as well as integrated products illustrating snowpack, precipitation, streamflow, and the potential for drought conditions. El Niño Southern Oscillation forecasts (which have demonstrated seasonal- to biennial-scale forecast skill) have provided information for State and local emergency preparedness organizations; water resource management plans for the western regions; agricultural planning for the southeast; and fire management. Federal agencies also employ decision-support tools to serve the public in local and regional decisionmaking, including applications in the management of carbon, water, disasters, invasive species, and coastal ecosystems along with information on public health, agricultural efficiency, and energy use.

Developing the sophisticated types of information (integrating physical, hydrological, ecological, demographic, and economic information) in the sustained fashion that is often needed to make complex adaptive management and planning decisions requires that scientists work side-by-side with managers and other stakeholders in the context of specific decisionmaking processes. These interactions are more effective when they occur through long-term partnerships in which targeted information is produced through research, incrementally incorporated into decisionmaking, then updated or

SYNTHESIS AND ASSESSMENT PRODUCTS 5.1 AND 5.3
Developing Tools and Methods to Support Adaptive Management/Planning

Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions. Synthesis and Assessment Product 5.1 will inventory and characterize the types, capacity, and reliability of observational and other information accessible for decisionmaking as a result of U.S. investments in climate change research. It will result in a catalog of demonstration projects and experiments for international, national, regional, and local decision-support objectives. The product will provide detailed profiles of projects selected from among those implemented by CCSP agencies deemed to be of significant regional or national societal benefit. The report will analyze the capacity and performance of demonstration projects that incorporate observations from remote sensing and *in situ* instrumentation (including measurements related to atmospheric conditions, climate, land-use/land-cover change, hydrology, ecosystems, and human activity) into decision-support tools. The focus of the assessments will be expanded in a subsequent phase to include a profile of the capacity of decision processes and tools to assimilate forecasts and projections resulting from climate change science.

Decision-Support Experiments and Evaluations using Seasonal-to-Interannual Forecasts and Observational Data. Synthesis and Assessment Product 5.3 will provide an evaluation of selected decision-support experiments that use seasonal-to-interannual climate information to support water management decisions. The product will explore the extent to which multidisciplinary research, conducted in consultation with water resource managers, can be designed and implemented to result in expanded decision options and improved management. The product will focus on the issue of water resources as an initial case study because of its inherent importance, the broad array of ongoing projects in the field, and the maturity of interactions between researchers and water resource managers. This product will document the experiences garnered in partnerships among scientists and stakeholders and thus contribute to knowledge of how to effectively integrate the insights of science with the information needs of decisionmakers.



extended through new research and information gathering. CCSP agencies are exploring development of these sorts of research and decision-support partnerships in diverse settings ranging from bi-national watershed planning to management of fisheries and other biotic resources.

Related HCR Research on Adaptive Management and Planning

Research on tools to support adaptive management and planning focuses on a variety of topics including factors that affect the ability of societies to respond to changes in climate and related systems and that thus influence their resilience or vulnerability. For most types of impacts, this field of inquiry has extended scenario-based modeling of potential impacts on natural and human systems (e.g., crops, forests, water flows, coastal infrastructure) by integrating additional information on sensitivity and adaptability from many sources, including operational entities, to support evaluation of responses. For example, a high priority for research and assessment of the potential implications of sea-level rise for the United States involves examining the interaction of sea-level rise, elevation, and approaches in different locations to zoning and planning. Reporting on this work is the focus of one of the CCSP synthesis and assessment products, on coastal elevation and sea-level rise.

SYNTHESIS AND ASSESSMENT PRODUCT 4.1

Coastal Elevation and Sensitivity to Sea-Level Rise. Data on the implications of sea-level rise are needed to inform decisions about both greenhouse gas emissions and how best to prepare for and adapt to sea-level rise. This product focuses on developing tools to support shore-protection and land-use decisions that are mostly made at the local level or on a parcel-specific basis. Many institutions and groups are developing data that can provide insights regarding the implications of sea-level rise, but this information is fragmented and needs to be integrated. The *CCSP Strategic Plan* includes two related geographic information system (GIS) products: maps of coastal elevations relative to sea level, and planning maps depicting how State and local governments could respond to sea-level rise. The Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and several States are developing elevation data for floodplain management. Local governments and major coastal conservancies are developing GIS land-use data for managing ecosystems and economic growth. The Department of Interior develops wetland and shore-erosion data. NOAA and USGS are developing technologies to produce digital elevation models using a common vertical reference frame, thus producing true topographic/bathymetric map products. This report will bring together these ongoing mapping efforts by Federal and non-Federal researchers. Because of time, data, and resource limitations, the synthesis will focus on a contiguous subsection of the U.S. coastal zone. The report will also develop a plan for a sea-level rise research program to answer the questions that are most urgent for near-term decisionmaking. Questions regarding the magnitude of past and future global sea-level rise are outside the scope of this report.

Highlights of Recent Research

Selected examples of recent CCSP-supported research to develop decision-support resources for adaptive management and planning follow.

Resources to Improve Drought Management.[2,21] Drought is an episodic natural disaster of potentially major proportions. Annual economic losses for the United States can be in the range of several billion dollars. As the recent prolonged drought in the western United States illustrates, drought impacts extend well beyond direct effects on water quantity and quality, with potentially significant consequences for energy generation (hydropower), agriculture, ranching, recreation and tourism, and the health of forests, range lands, fisheries, and other ecosystems.

CCSP has been working to increase partnerships with stakeholder groups to bring advances in climate science to bear on how society can better anticipate, prepare for, and respond to the challenge of drought. A major focus for these efforts is a cooperative effort led by the Western Governors' Association (WGA), with leadership on the Federal side from NOAA in partnership with several other CCSP agencies including USGS, Bureau of Reclamation, and USDA. Other participants include the National Interagency Fire Center, the Western States Water Council, the Interstate Water Council, The Nature

Conservancy, and the Office of Science and Technology Policy. As a result of this collaboration, in 2004, the WGA produced a report with unanimous approval of the governors that describes key steps necessary to develop and implement the National Integrated Drought Information System and what is required to move the Nation from a reactive to a proactive approach to anticipating, preparing for, and responding to drought and its attendant impacts (see Figure 24). CCSP-supported research is expected to play a fundamental role in developing this new national capability, with particular needs for improved observational, monitoring, and prediction capabilities, and the development of new tools for decision support.

In addition, CCSP has been examining the potential implications of regional drought on crop production. Using radar altimetry data from NASA's TOPEX/Poseidon and Jason-1 Earth observation spacecraft, researchers from NASA, USDA, and the University of Maryland estimated reservoir height and water volume in approximately 100 lakes and reservoirs across the world's major agricultural regions to determine irrigation potential in agriculture-sensitive regions, and as a general indicator of drought or high-water condition. The reservoir height data are used now by analysts in the Production Estimation and Crop Assessment Division of the USDA Foreign Agriculture Service. The World Agricultural Outlook Board uses these condition estimates in forecasts of global agricultural commodities that they regularly publish.

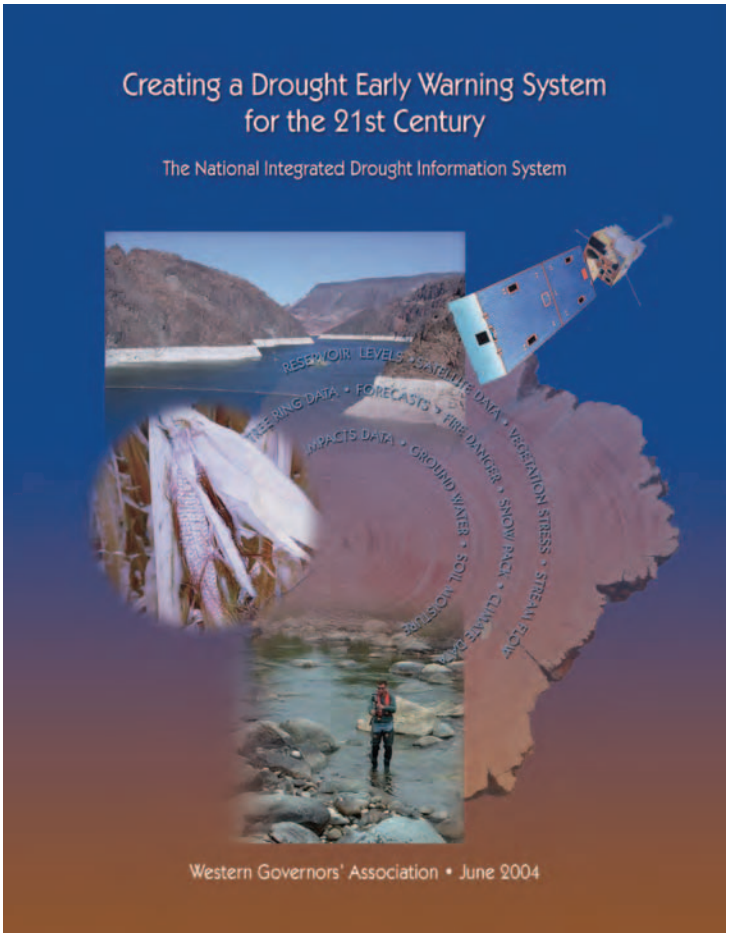
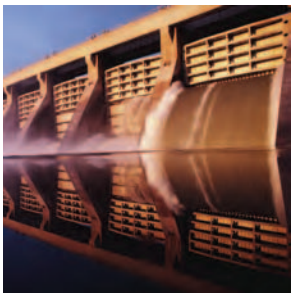


Figure 24: The National Integrated Drought Information System. The report of the Western Governors' Association describing the components necessary for a National Integrated Drought Information System. *Credit: Western Governors' Association*.



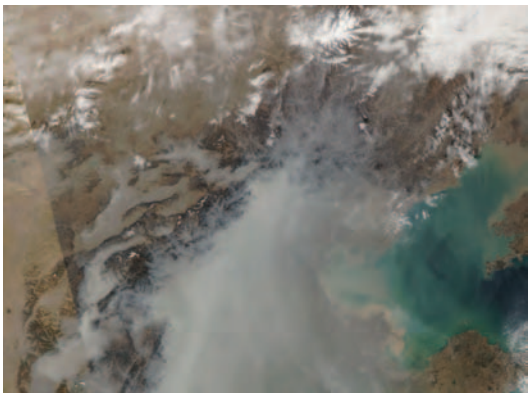
Climate Change Scenarios for Water Resource Managers.[6] Water resource planners are beginning to ask how climate change might affect specific water resource systems. Reductions in mountain snowpack, which provide large amounts of natural storage for water resource systems in regions such as the Pacific Northwest, are likely at risk from future warming (see the "Climate Variability and Change" and "Global Water Cycle" chapters). Estimates of future warming rates are by themselves of little use to planners, who require watershed-specific information that they typically obtain from simulation models based on historic streamflow data. CCSP-supported university research scientists have found a way to bridge the gap between climate science and traditional water planning practices, providing useful information to water managers regarding river flow projections. These scenarios have allowed planners to compare the impacts of warming-adjusted streamflows with those of a portion of the historic record to see how climate change would affect their ability to meet various water resource objectives such as urban water supply, irrigation, and hydropower.

Climate Change and Coral Bleaching: Understanding Reef Resilience for Management Planning.[19,22] Large-scale coral bleaching events have been increasing in severity and extent over the past 2 decades. These events cannot be fully explained by localized stressors such as pollution, and instead appear to be linked to the presence of increased sea surface temperatures (Wilkinson, 1998; West and Salm, 2003). While reef managers cannot directly address increases in sea surface temperature linked to climate variability and change, they can engage in adaptive management that takes advantage of knowledge of why some reef areas are less affected by temperature anomalies than others. Three collaborative projects are providing information to assist coral reef managers in the strategic design, placement, zoning, and management of networks of marine-protected areas that maximize reef resilience in the face of climate change. These include: (1) a project to identify environmental factors that may increase resilience by conferring protection from bleaching or enhancing recovery after bleaching; (2) a monitoring project in American Samoa that examines the effects of changes in water quality and different levels of reef protection on coral bleaching and recovery; and (3) a multi-agency cooperative that synthesizes research information to promote adaptive management of coral reefs in response to climate change

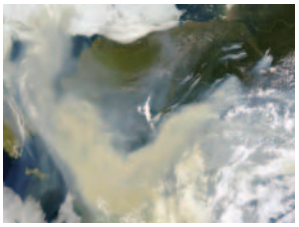
Use of Climate Variation to Forecast Mosquito Abundance and Encephalitis Risk in California.[1,4] The amplification of encephalitis viruses to levels that place human populations at risk of infection depends in part on temperature-related factors. Research is underway that uses climate forecasting at various spatial scales to alert local and state public health officials to changing risks of encephalitis infection. A risk model has been developed that characterizes climate factors related to encephalitis outbreaks (e.g., indicators for rainfall, runoff, and temperature). The

model demonstrates that mosquito abundance patterns and associated patterns of encephalitis risk vary spatially across the different biomes of California and show strong links to climate variations (Barker *et al.*, 2003). The California Mosquito-Borne Virus Surveillance and Response Plan provides a means for estimating the risk from two endemic encephalitides [western equine encephalomyelitis (WEE) and St. Louis encephalitis (SLE)] and describes intervention guidelines for mosquito control that public health agencies can use during periods of heightened risk for human infection. These risk models provide a means for calculating a risk estimate for WEE and SLE infection and a basis for prescribing appropriate response strategies to protect public health.

Improved Air Quality Forecasts. EPA has partnered with NASA and NOAA to improve its air quality index for current conditions ("nowcasts") and forecasts for the next 30 hours by assimilating data from NASA's Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument flown on the Terra and Aqua spacecraft (see <idea.ssec.wisc.edu/index.php>). EPA and NOAA signed a cooperative agreement in May 2003 to coordinate the development of air quality forecast guidance. The improved forecasts of air quality and pollution are integrated into a prototype tool that is delivered via the internet (see <www.epa.gov/airnow>). EPA recently integrated the prototype tool into its AIRNow Forecaster Training Workshops, providing training to over 200 air quality forecasting professionals throughout the country. Air quality information is not only important for health-advisory purposes; aerosols (fine particles), tropospheric ozone, and other short-lived air pollutants are also recognized as potential climate forcing agents.



Decision-Support Resources for Ecosystem and Carbon Management Applications.[15] Researchers evaluated results from an integrated model and decision-support tools that help inform decisions related to ecosystem and carbon management. Using vegetation data from MODIS instruments on board the Terra and Aqua spacecraft, NASA's Carnegie-Ames-Stanford Approach (CASA) model predicts photosynthesis rates, the amount of vegetation and living organisms within a unit area, and estimates of organic matter that forms the litter layer in soil. The Carbon Query and Evaluation Support Tools (CQUEST) tool provides Internet access for decisionmakers to display, manipulate, and save CASA model estimates of carbon sinks [reservoirs that absorb and store carbon dioxide (CO_2) from the atmosphere] and CO_2 fluctuations in agricultural and forest ecosystems for locations anywhere in the United States (see <geo.arc.nasa.gov/website/cquestwebsite>). USDA Forest Service is currently evaluating CQUEST for monitoring carbon sequestration and loss through forest disturbance and regrowth.



Climate Variability and Fires.[3,7,10,17,18,20] Climate connections to fire severity appear to occur through the effects of varying moisture patterns in producing higher or lower than normal amounts of grass in the preceding 2 years, and from the dryness of the vegetation. CCSP-supported scientists are studying these climate and wildfire interactions on a regional scale for the western United States (Roads *et al.*, 2004; Reinbold *et al.*, 2004), and developing long-lead forecasts for use by wildfire managers (Brown *et al.*, 2003). Westerling *et al.* (2002) compiled a comprehensive 21-year fire history for the western United States to facilitate climate-based predictions of the potential severity of the fire season several months in advance. Numerous steps are being taken to bring this scientific information to relevant decisionmakers. For example, two workshops are held each year – one focused on eastern and southern states and the other on western states and Alaska – involving climate scientists and wildfire managers (e.g., the National Interagency Fire Center) to provide and discuss the climate outlook for the upcoming fire season (Lenart *et al.*, 2005; Garfin *et al.*, 2004). Further information on these workshops may be obtained from <www.ispe.arizona.edu/climas/conferences/NSAW/index.html>.

Famine Early Warning System Network. The United States supports the innovative application of science to alleviate risks related to existing climate variability or the potential for climate change through the Famine Early Warning System Network (FEWS NET; see <www.fews.net>). FEWS NET provides decisionmakers with the information to respond effectively to drought and food insecurity by analyzing remote-sensing data and ground-based meteorological, crop, and rangeland observations to identify early indications of potential famine. In addition to using data produced by host governments for its analyses, FEWS NET uses data from satellite imagery [Normalized Difference Vegetation Index (NDVI) or "greenness" images and Meteosat Rainfall Estimation images] that it receives every 10 days throughout the year. FEWS NET operates in 20 countries in Africa, three countries in Central America, and in Haiti and Afghanistan.

Highlights of Plans for FY 2006

In FY 2006, CCSP participating agencies will sponsor research to develop decision-support resources for adaptive management and planning for responding to climate variability and change, and develop collaborations to apply these research-based resources in operational settings. Selected examples follow.

Use of Seasonal-to-Interannual Climate Information. Research on the use of seasonal-to-interannual climate information will focus on mitigating the impacts of short- and long-term droughts, as well as assessing risks involved in upcoming wildfire

DECISION-SUPPORT RESEARCH: BRIDGING SCIENCE AND SERVICE
The Regional Integrated Sciences and Assessments Program

The Regional Integrated Sciences and Assessments (RISA) Program is composed of eight teams of researchers who investigate the potential impacts of seasonal-to-interannual and longer term global change, and collaborate with local, State, and Federal agencies tasked with specific resource management mandates. Through a process of interaction with key regional stakeholders – such as public health agencies, water resource managers, fishers, extension agents, and farmers – researchers address climate-sensitive issues relevant to a variety of policy and natural resource management goals. Findings from RISA activities and the development of experimental decision-support tools are proving highly valuable in a range of practical settings. Examples of research-based products include:

- The incorporation of model-based climate information into the production of regional maps for fire risk and forest management (Lenart *et al.*, 2005)
- Snow-water equivalent forecasts for the San Francisco Bay Delta watershed that have been used by CALFED – a consortium of 23 Federal and State agencies that are collaborating to restore the San Francisco Bay estuary and an adjacent major inland delta – in efforts to determine trends in water supply and demand (Dettinger *et al.*, 2004)
- Long-lead streamflow forecasts for water resource planning associated with the Columbia River (Hamlet *et al.*, 2002)
- AgClimate, a web-based decision-support system to help farmers manage risks associated with climate variability (<agclimate.org>)
- University curricula for the multidisciplinary study of climate impacts and policy response, used to educate the next generation of students of public policy and resource management (<www.cses.washington.edu/cig/outreach/classes.shtml>).

Meeting the climate information needs of decisionmakers is a major challenge. In addition to mastering the ability to observe, understand, and simulate continental- and global-scale processes, the ultimate utility of this work hinges on making the connection between regional variability and humans or ecosystems. Regionally based programs, such as RISA, utilize studies of the application of climate information and rely on human-dimensions research to strengthen the theoretical foundations of decision support.

These activities address Question 9.2 and Goal 11.2 (Objective 2.1) of the CCSP Strategic Plan.

seasons. Work will be aimed at water management, wildfire management, and drought planning, and will emphasize how scientific information about climate and drought impacts can be used to inform decisionmaking at State, regional, and national levels. Through the Regional Integrated Sciences and Assessments (RISA) Program, two workshops with researchers and fire managers will be held in 2006 to assess upcoming fire seasons and plan more effectively. Several workshops with local and State water managers will also be held in the western United States in 2006. In addition, the recently initiated NOAA Climate Transition Program will review a round of proposals in early FY 2006 to address the increasingly important challenge of applying decision-relevant climate research in operational settings. Operational settings include, but are not limited to, water management agencies, fisheries councils, disaster management offices, and weather service field offices.

These activities will address Question 9.2 and Goal 11.2 (Objective 2.2) of the CCSP Strategic Plan.

Early Snowmelt Discharge and its Effects on Water Resources in the Western United States. Research in the USGS Earth Surface Dynamics Program will address the implications of climate-induced early snowmelt discharge and its effects on water resources in the western United States. A decision-support system

(DSS) will be developed to evaluate the risks associated with management choices in the face of climate variability, with a focus on sample reservoir systems on the western slope of the Sierra Nevada. The research will compare the economic efficiency of managing reservoirs with and without better data, models, and predictive capacity, and will estimate the value of improved forecasts of water resource availability in the Sierra Nevada under changing climatic conditions using the DSS. Further research will evaluate the tradeoff between the cost to a decisionmaker of an inaccurate climate policy, management, or investment decision and the cost to the decisionmaker of seeking a better decision.

These activities will address Questions 4.2, 4.5, 5.5, and 9.3 of the CCSP Strategic Plan.

Decision Support for Public Health Decisionmakers. Several 3-year research projects will address how climate change and health impact studies can be transformed into information useful to public health decisionmakers. The studies will employ partnerships between researchers and decisionmakers in the public health arena (see <es.epa.gov/ncer/rfa/2005/2005_decision_support_sys.html>). Additional studies will address two priority research areas: (1) heat- and cold-related illnesses, and (2) waterborne diseases. A better understanding of the consequences of climate variability and change for human health will be useful for State and local public health agencies' efforts to ameliorate these effects (see <es.epa.gov/ncer/rfa/2005/2005_hsa_impacts_research.html>).

These activities will address Question 9.4 of the CCSP Strategic Plan.

Coastal Elevation Maps and State and Local Plans for Sea-Level Rise. Coastal elevation maps that depict areas vulnerable to sea-level rise are being produced by the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, EPA, NOAA, USGS, and several States. Planning maps are being created by EPA that synthesize current State and local baseline plans for sea-level rise along the U.S. Atlantic Coast. This work improves understanding of the sensitivity and adaptability of coastal ecosystems and human systems and provides resources to support coastal zone environmental and infrastructure-related decisionmaking. These maps will synthesize current State and local coastal policies along the U.S. Atlantic and Gulf Coast. Conservation officials will be able to use the maps to determine whether current policies ensure sufficient wetland migration, and identify areas where additional wetland migration is feasible. Local governments can focus infrastructure in areas where shores are certain to be protected. Ecologists studying potential environmental consequences of climate change will have a better idea whether tidal habitat will shift inland or be replaced with seawalls. During FY 2005-2006, existing draft maps that have already been reviewed by local stakeholders in mid-Atlantic cities and counties will be peer-reviewed and published, and new maps will be created along the south

Atlantic and New England Coasts, as well as the Gulf Coast of Florida. This work will support preparation of CCSP Synthesis and Assessment Product 4.1.

These activities will address Question 9.2 of the CCSP Strategic Plan.

Early Warning System for the Rapid Identification of Health Threats.[12] Scientists plan measurable enhancements to the Centers for Disease Control and Prevention (CDC) Environmental Public Health Tracking Network/Health and Environment Linked for Information Exchange (EPHTN/HELIX) decision-support system using NASA Earth-Sun System research results. This epidemiological surveillance decision-support system is designed to establish a national network of local, State, and Federal public health agencies that tracks trends in priority chronic diseases. Planned to be fully functional around 2009, the EPHTN will be a national early warning system for the rapid identification of health threats, such as toxic chemical releases. Earth science results provide valuable information on the environmental contribution to chronic diseases, and forecasts based on coupled Earth system-chronic disease models. The plan for 2006 includes determining the performance of the EPHTN/HELIX decision-support tool configured to assimilate observations from NASA Earth-observing sensors MODIS and ASTER, and forecasts of Earth system processes from the Large Scale Eddy Simulation Model. This work will enhance the ability of the EPHTN/HELIX surveillance system to assimilate observations and predictions of weather, climate, and environmental risk factors to predict disease events and to more accurately represent environmental risk factors.

This activity addresses Questions/Goals 9.3, 9.4, 11.1, and 11.2 of the CCSP Strategic Plan.

Mesoamerican Biological Corridor. NASA, USAID, the World Bank, and the Central American Commission for Environment and Development are partnering to develop a regional visualization and monitoring system. The Central America Monitoring and Visualization System (SERVIR) is a decision-support tool that will assist the seven nations of Central America in developing a Mesoamerican Biological Corridor extending from southern Mexico to the Colombian border. SERVIR uses assimilated remote-sensing Earth observations of environmental and other geophysical parameters in a geographic information system that generates visualization products

for decisionmakers to aid in ecosystem management. SERVIR's users are government policymakers and natural resource managers, nongovernmental organizations, teachers, students, and the general public. Specific decision-support products include fire detection, red tide location, hurricane tracking, food security early warning system, and climate change modeling. These products reach users through a series of information nodes located in each of the participating countries. More information on SERVIR is available at <servir.nsstc.nasa.gov/home.html>.

This activity supports Questions 8.1, 8.2, and 8.3, as well as Goals 11.1 and 11.2 of the CCSP Strategic Plan.

Decision-Support Resources Goal 3: Policy Decisions

"Policy decisions" can result in laws, regulations, and other public actions. These decisions are typically made in government settings by elected or appointed officials. Policy-related questions regarding climate change typically arise from numerous sources, for example from:

- Consideration of climate change policy within the Federal government
- Proposals advanced by private and non-governmental organizations
- Preparation for international negotiations
- Consideration of legislative proposals
- Priority-setting processes for science and technology programs.

As described in the *CCSP Strategic Plan*, CCSP is focusing on two objectives in this area: (1) developing scientific syntheses and analytical frameworks to support integrated evaluations, and (2) initially conducting a limited number of case studies with evaluation of the lessons learned to guide future analyses.

CCSP supports the development of a number of integrated modeling frameworks that are useful for exploring many dimensions of climate and global change. Integrated analysis of climate change is essential for bringing together research from many contributing disciplines and applying it to gain comparative insight into policy-related questions. Full integration of information including research on human activities, greenhouse gas and aerosol emissions, land-use and land-cover change, cycling of carbon and other nutrients, climatic responses, and impacts on people, the economy, and resources is necessary for analysis of many important questions about the potential economic and environmental implications of changing greenhouse gas concentrations and various technology portfolios. Development and use of techniques for scenario and comparative analysis are useful for exploring the implications of different hypothetical

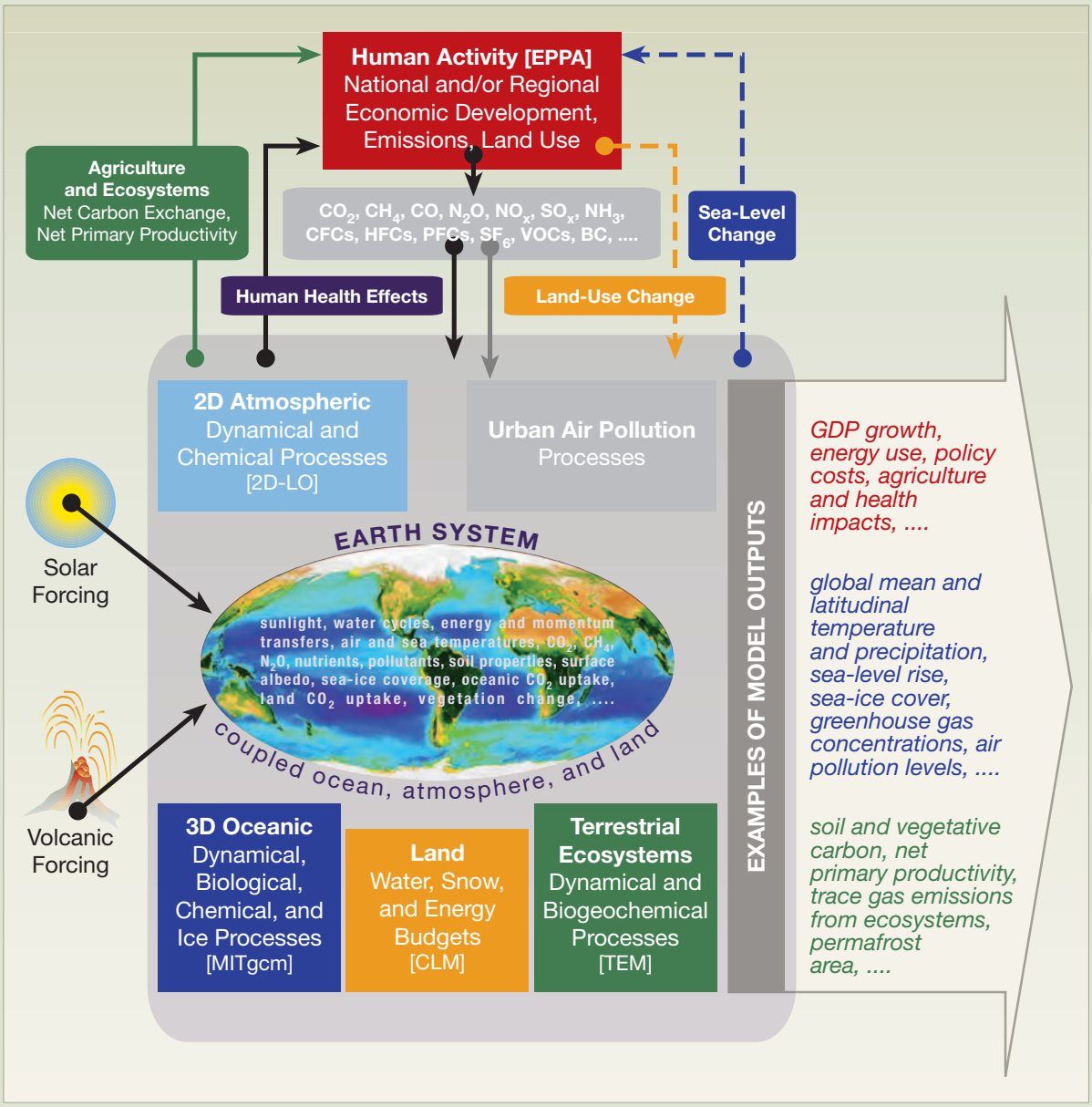
policies for curbing emissions growth or encouraging adaptation. Answers from integrated analysis can only reflect the existing state of knowledge in component studies, but it is important to develop frameworks and resources for integration, exercise them, and learn from analysis of the results. CCSP is encouraging innovation and development of approaches to integrated analysis.

An integrated assessment of climate change analyzes the human (including economic), physical, and biological aspects of climate change, from the forces that give rise to greenhouse gas emissions or land-cover/land-use change (such as economic activity, population and demographic change, and technological advance), through emissions, to impacts (such as changes in unmanaged ecosystems, sea-level rise, and altered growing conditions for crops). The primary emphasis in an integrated assessment is to represent all three aspects in such a way that the costs and benefits of climate change can be evaluated. Integrated assessments are commonly based on scenarios simulated using a computer model. Integrated assessment models are used to evaluate, for example, specific climate change policy options, including those for reducing greenhouse gas emissions.

Under CCSP, the DOE Integrated Assessment of Climate Change Research Program sponsors academic investigators who examine individual research topics using integrated assessment models. DOE sponsors the development of several integrated assessment models, and EPA, NOAA, and NSF sponsor additional studies that improve aspects of models and allow for the use of the models for particular investigations. Two major integrated assessment modeling teams are supported – one at the Massachusetts Institute of Technology and the other at the Pacific Northwest National Laboratory. CCSP does not make policy recommendations. Instead, it supports fundamental research that provides necessary objective background understanding for others to analyze policy questions and make policy recommendations.

INTEGRATED ASSESSMENT MODELS

The schematic illustrates the framework and components of a typical integrated assessment model. This particular model was developed by the Massachusetts Institute of Technology (see <mit.edu/globalchange/www/if.html>). An economic model (often a general equilibrium model) provides emission scenarios, which are used as inputs to atmospheric chemistry and climate models. Outputs from the atmospheric models are used as inputs to models that evaluate the impact of potential future climate change on agricultural, ecosystem, and other sectors. For example, in the schematic the climate model outputs drive a terrestrial ecosystems model projecting land vegetation changes, land CO_2 fluxes, and carbon storage, which feed back to the coupled chemistry/climate and natural emissions models. There are a variety of feedbacks between the component models. In view of the large number of analytical elements in an integrated assessment model, each with its own uncertainties, the outcomes of these models must be carefully evaluated for their overall uncertainties.



SYNTHESIS AND ASSESSMENT PRODUCT 2.1

Updating Scenarios of Greenhouse Gas Emissions and Concentrations, in Collaboration with the Climate Change Technology Program (CCTP): Review of Integrated Scenario Development and Application. Scenario analysis is a widely used intellectual device for decisionmaking in complex and uncertain situations. Scenarios have been applied extensively in the climate change context. Examples include emissions scenarios, climate scenarios, and technology scenarios. Scenarios are not predictions; they are "what ifs?" – sketches of future conditions (or alternative sets of future conditions) – used as inputs to decisionmaking or analysis exercises.

Synthesis and Assesssment Product 2.1 has two components. Part A will use integrated assessment models as the foundation for a small group of new global emissions scenarios leading to long-term stabilization of greenhouse gas concentrations. These new scenarios will incorporate lessons from previous scenario efforts and will be based on the evolving state-of-the-art in integrated assessment modeling. The scenarios are intended for policymakers and analysts, such as the technology analysts in the CCTP, who may benefit from enhanced understanding of the role of technology in stabilization; other decisionmakers or analysts, such as climate modelers, who may use the data outputs of the scenarios as inputs to analyses (e.g., climate modelers might use the emissions trajectories as inputs to climate models); and analysts or decisionmakers who may use the participating integrated assessment models to generate additional analyses, using the scenarios as a foundation (e.g., using the integrated assessment models to explore the implications of various additional scenarios of technological advance). Part B will review and evaluate how the science and stakeholder communities define, develop, implement, and communicate scenarios in the global climate change context, and how this process might be enhanced or improved. This will include a review of past scenario development and application efforts. The intent of the review is to inform preparation and application of future scenarios by CCSP, the IPCC, the CCTP, and other global change research and assessment organizations.

An initial case study of the application of integrated assessment tools is being undertaken in Synthesis and Assessment Product 2.1. Other case studies focus on practices to increase soil carbon levels and transportation policy options for responding to climate change, as follows.

Alternative Incentive Designs for Practices to Raise Soil Carbon Levels.[11] Atmospheric concentrations of greenhouse gases can be reduced by withdrawing carbon from the atmosphere and sequestering it in soils and biomass. Research analyzed the performance of alternative incentive designs and payment levels if farmers were paid to adopt land uses and management practices that raise soil carbon levels.

Transportation Policy Options for Responding to Climate Change. Under a new study, *Climate Change and U.S. Transportation*, the Transportation Research Board (TRB) and the Division of Earth and Life Sciences of the National Academies will evaluate transportation policy options for adapting to the potential impacts of climate change, and examine strategies to mitigate future climate impacts. DOT, EPA, the U.S. Army Corps of Engineers, and TRB (including the American Association of State and Highway Officials and the Transit Cooperative Research Program) are sponsoring the study, which will include as a centerpiece a major conference with commissioned papers that is designed to foster and expand dialog and awareness about the potential risks and consequences of climate change. A committee of experts assembled for this effort will issue a report with findings and recommendations regarding needed research and actions.

SYNTHESIS AND ASSESSMENT PRODUCT 4.7

Impacts of Climate Variability and Change on Transportation Systems and Infrastructure. A sound transportation system is vital to the Nation's social and economic future. Investments in transportation are substantial, and result in infrastructure that lasts for decades. This product will investigate the potential impacts of climate variability and change on transportation infrastructure and operation, and provide guidance as to how transportation planners and decisionmakers may incorporate this information into transportation planning, design, engineering, and operational decisions to ensure a reliable and robust future transportation network. Implications for all transportation modes – surface, marine, and aviation – will be addressed. This initial study will focus on the potential effects of climate variability and change on transportation infrastructure and systems in the central U.S. Gulf Coast. It will also include a review of knowledge of the potential impacts of climate change on national transportation systems.

The three-phase study will:

- Develop knowledge about potential transportation infrastructure sensitivities to climate variability and change through an indepth synthesis and analysis of existing data and trends
- Assess the potential significance of these sensitivities to transportation decisionmakers in the central U.S. Gulf Coast region
- Identify potential strategies for adaptation that will reduce risks and enhance the resilience of transportation infrastructure and services
- Identify or develop decision-support tools or procedures that enable transportation decisionmakers to integrate information about climate variability and change into existing transportation planning and design processes.

HCR Research on Human Contributions to Global Change: Relevance to Informing Policy Inquiries

Research on human contributions to global change can have direct bearing on the development of decision-support resources and methods for informing climate change policymaking (i.e., Decision-Support Goal 3; see chapter banner). This work draws upon analyses of fundamental socioeconomic processes and spans a range of disciplines and topics, including demography, economics, history, anthropology, political science, and engineering. This research examines factors affecting greenhouse gas emissions (e.g., energy use) and changes in land use and land cover. Recent research has also focused on the factors that affect environmentally significant consumption at the household level, as well as on understanding trends in innovation, efficiency, and living standards, and their implications for energy use, emissions, and land-use/land-cover change.

For example, research on demographic and energy data in China, the United States, and Indonesia used household surveys and disaggregated energy use data to improve the prediction of energy use by fuel type. The research is designed to provide data and information on the demographic and technology factors that drive energy use and the associated emissions of greenhouse gases in three case-study countries that have large populations and are currently or will soon become major global sources of greenhouse gas emissions. One example of results from this research to date is evidence that the shift in rural China and elsewhere from the use of traditional fuels such as firewood for home heating and cooking to commercial fuels such as fossil fuels may not be as

sensitive to income level as previously assumed and therefore may occur somewhat more slowly than commonly thought (Jiang and O'Neill, 2004).

In another example, researchers from the Center for the Study of Institutions, Population, and Environmental Change at Indiana University working in Brazil have extended consideration of the role of household demography in land-use decisions (Deadman *et al.*, 2004). They used a household life-cycle model that examined the relationships between household age and land use and between time since acquisition of the property and land use in regions around the Brazilian cities of Altamira and Santarém. The researchers found that in Altamira, younger households deforest at higher rates, whereas older households, which may have undergone earlier episodes of deforestation, tend to consolidate into perennials and pasture. In Santarém, a study area with a much longer but less planned settlement history, the age of the household showed no relationship with land use. In both locations, the time since acquisition of the lot was more strongly related to deforestation than household age (even in Altamira), suggesting that lot turnover is in fact a key driver of land-use change in both locations.

Highlights of Plans for FY 2006

Integrated Assessment of Aerosol Production, Effects, and Control. In FY 2006, Argonne National Laboratory will develop new estimates of future aerosol emissions for sulfur and carbonaceous aerosols. This work will address technology types not often considered in forecasting models, such as cookstoves in developing countries. Other researchers at the Massachusetts Institute of Technology will investigate aerosol effects on radiation absorption and reflection and on the hydrologic cycle by analyzing the economics of aerosol production and control, the atmospheric chemistry and radiation effects of these substances, and the interaction with terrestrial systems (including hydrological effects). These studies are supported by the DOE integrated assessment (IA) program.

This work will address Question 9.1 of the CCSP Strategic Plan.

Representation of Uncertainty in Emission Scenarios for Integrated Assessment of Climate Change. In FY 2006, researchers at the University of North Carolina, as a part of the DOE IA program, will contribute data and methods to support improved representation of uncertainty in the future development of emission scenarios for integrated assessment of climate change and other purposes. Historical data on energy use will be used to characterize uncertainties in measures of substitution between energy and other inputs such as capital and labor. Probabilistic scenarios of emissions will be explored by propagating uncertainty in emissions

through a climate-chemistry model and testing various criteria for selecting a small number of emissions scenarios that span the scenario probability space.

This work addresses Question 9.3 of the CCSP Strategic Plan, and will support Synthesis and Assessment Product 2.1.

Integrated Assessment of Climate, Land and Water Resources, and Economic Activity. Throughout the last decade, USDA's Economic Research Service (ERS) has analyzed how global changes might affect long-term agricultural and environmental sustainability. For much of this research, ERS has relied on the Future Agricultural Resources Model (FARM), an integrated modeling framework. FARM has been used primarily to analyze the impacts of greenhouse gas emissions on agriculture, but has also been used to explore other topics such as costs of sea-level rise, the effects of trade deregulation and population growth on tropical forests, the costs of protecting global ecosystem diversity, and the impacts of technological advance in agriculture on land use. ERS has initiated the Economic Evaluation of Changes in Earth's Land and Water Resources Project to revise the FARM modeling framework. A revised, documented database and a user manual for a prototypical revised model will be available to the public in FY 2006. The new modeling framework itself will assist researchers and decisionmakers in addressing questions from the *CCSP Strategic Plan* related to water resources, land-use and land-cover changes, ecosystems, and human contributions and responses to environmental change.

This activity will directly address Goal 11.2 of the CCSP Strategic Plan.

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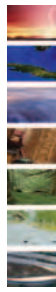
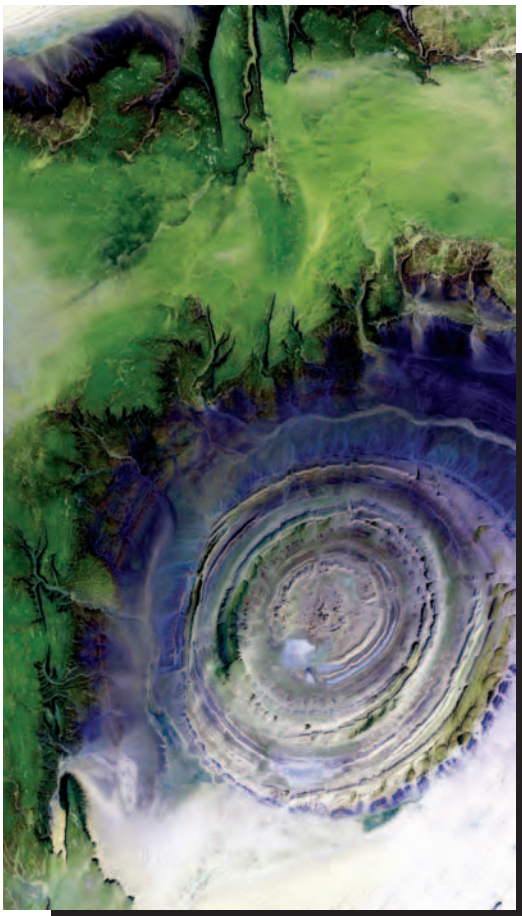




8 Observing and Monitoring the Climate System

Observing and Monitoring the Climate System

Goal 12.1: Design, develop, deploy, and integrate observation components into a comprehensive system.
Goal 12.2: Accelerate the development and deployment of observing and monitoring elements needed for decision support.
Goal 12.3: Provide stewardship of the observing system.
Goal 12.4: Integrate modeling activities with the observing system.
Goal 12.5: Foster international cooperation to develop a complete global observing system.
Goal 12.6: Manage the observing system with an effective interagency structure.

Data Management and Information

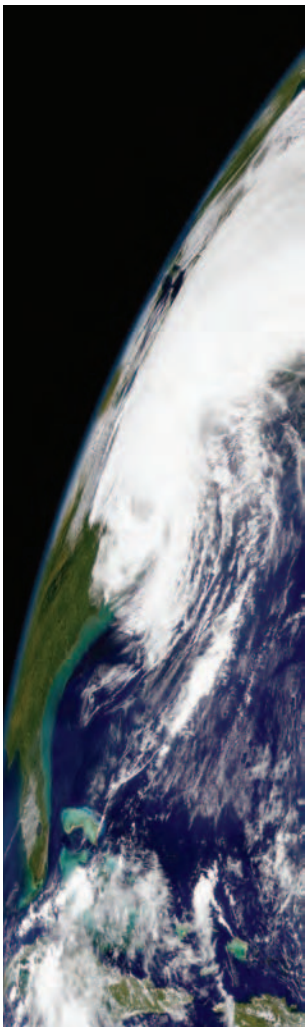
Goal 13.1: Collect and manage data in multiple locations.
Goal 13.2: Enable users to discover and access data and information via the Internet.
Goal 13.3: Develop integrated information data products for scientists and decisionmakers.
Goal 13.4: Preserve data.

See Chapters 12 and 13 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these goals.

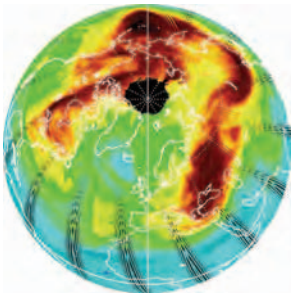
The CCSP Strategic Plan identifies two overarching questions for "Observing and Monitoring the Climate System" (Chapter 12) and "Data Management and Information" (Chapter 13):

- How can we provide active stewardship for an observation system that will document the evolving state of the climate system, allow for improved understanding of its changes, and contribute to improved predictive capability for society?
- How can we provide seamless, platform-independent, timely, and open access to integrated data, products, information, and tools with sufficient accuracy and precision to address climate and associated global changes?

The United States is contributing to the development and operation of several global observing systems that collectively attempt to combine data streams from both research and operational observing platforms to provide a comprehensive measure of climate system variability and climate change processes. These systems provide a baseline Earth-observing system and include NASA, NOAA, and USGS Earth-observing satellites and extensive *in situ* observational capabilities. U.S. observational and monitoring activities contribute significantly to several international observing systems including the Global Climate Observing System principally sponsored by the World Meteorological Organization (WMO); the Global Ocean Observing System sponsored by the United Nations Educational, Scientific and Cultural Organization's Intergovernmental Oceanographic Commission; and the Global Terrestrial Observing System sponsored by the United Nations Food and Agriculture Organization. The latter two have climate-related elements being developed jointly with the Global Climate Observing System.

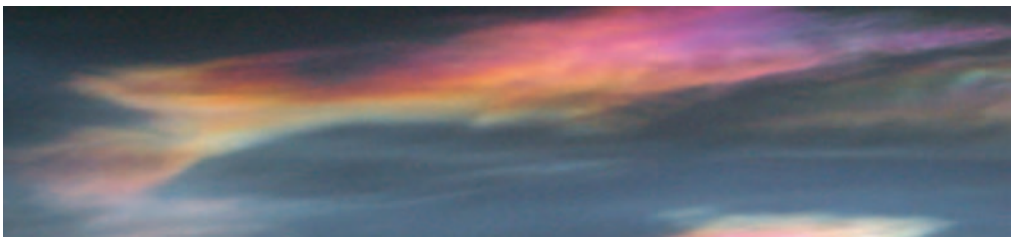


The United States is also playing an important role in the Global Earth Observation System of Systems (GEOSS), which is an international framework for coordinating and sustaining the aforementioned (and other) systems. Information from GEOSS is expected to revolutionize understanding of the Earth and how Earth observations may benefit society. A 10-year implementation plan for GEOSS was adopted in February 2005 by nearly 60 countries, including the United States (see <earthobservations.org> for a copy of this plan, as well as other information on GEOSS). The United States Group on Earth Observations (USGEO) has drafted a strategic plan for integrated Earth observations, which contributes directly to GEOSS. CCSP coordinates USGEO's climate and global change-related activities. USGEO is focusing on the following areas, many of which are directly or indirectly related to CCSP: understanding, assessing, predicting, mitigating, and adapting to climate variability and change; weather forecasting; reducing loss of life and property from disasters; protecting and monitoring ocean resources; supporting sustainable agriculture and combating land degradation; understanding the effect of environmental factors on human health and well-being; developing the capacity to make ecological forecasts; protecting and monitoring water resources; and monitoring and managing energy resources.



A critical challenge is to maintain existing observing capabilities in areas of importance to CCSP. For example, maintenance of the observational record of stratospheric ozone is essential to discern the nature and timing of expected ozone recovery. Other key variables requiring maintenance include radiative energy fluxes of the Sun and Earth, atmospheric carbon dioxide (CO_2) concentration, and global surface temperature. The long-term record of global land cover begun by Landsat-1 in 1972 and continued into 2003 by Landsat-7, ended with a mechanical failure in Landsat-7 on 31 May 2003. While Landsat-7 data are still being collected, 20% of the data contain holes and are not useable for scientific study. While scientists are looking to use other U.S. and international satellite instruments to provide interim land-cover data, a recognized need exists to ensure the continuing availability of high-quality land-cover measurements into the future. The details of an observing strategy to meet this requirement are under serious discussion now within the U.S. Government. The record of precipitation that has in recent years been extended to include oceanic as well as land areas using measurements from the Tropical Rainfall Measuring Mission (TRMM) is clearly a key climate data set that needs to be maintained and extended. These few examples of key climate variables are essential elements of the comprehensive observing system needed to monitor changes in the cycles of carbon, energy, water, and related biogeochemical processes that drive Earth's climate. Since the value of existing climate data sets greatly increases as the record is extended in time, it is imperative that existing observing capabilities be maintained and improved, while at the same time incorporating new requirements.

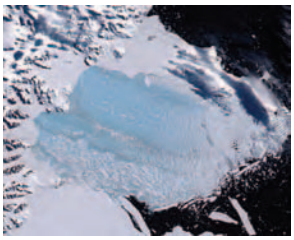
One of the priorities for observations and monitoring in FY 2006 is to further define the U.S. role in GEOSS, including the development of an information management system to help integrate the system's distributed resources. Another priority is to enhance observational capabilities in polar regions, both through remote sensing and *in situ* approaches. Observations of aerosols, including the Atmospheric Brown Cloud project (described in this chapter) and approaches outlined in the "Atmospheric Composition" chapter of this report, are also a priority. Improving understanding of the carbon cycle, which CCSP has identified as a near-term priority, will be facilitated by enhanced observations in FY 2006 and beyond. A longer list of some of the planned observational and monitoring activities is provided in the latter portion of this



chapter. Data management and distribution activities, including those mentioned in the box on "Systems for Data Management and Distribution," will play a key role in making accessible the information necessary to fulfill CCSP's mission to provide the "Nation and the global community with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems."

Many measurement and monitoring technologies and derived data systems benefit from the ongoing research and development under the aegis of CCSP, and from other Earth observation activities that are currently underway. All such measurement and monitoring systems constitute an important component of and complement to the measurement and monitoring research and development portfolio of the Climate Change Technology Program (CCTP). For additional information on CCTP measurement and monitoring research and development activities, see <www.climatetechnology.gov>.

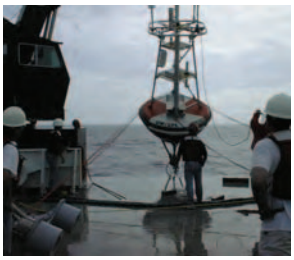
HIGHLIGHTS OF RECENT ACTIVITIES AND ACCOMPLISHMENTS



The following are selected highlights of observations and monitoring activities supported by CCSP participating agencies. The principal focus of this chapter is on describing progress in implementing the observations that contribute to the CCSP mission. As a result, the chapter touches on some observing systems that are crucial to CCSP but are not included within the CCSP budget because they primarily serve other purposes.

Observations and Monitoring

Global Climate Observing System (GCOS). GCOS integrates global networks placed strategically across the atmospheric, oceanic, and terrestrial domains, permitting better understanding of climate variability and change. In recent years, GCOS has accomplished a number of positive actions on international, regional, and bilateral levels that have led to success in improving climate observations worldwide. A number of workshops have been held in developing nations, highlighting the importance of GCOS observations. These workshops have resulted in a series of regional action plans that will help guide observational improvements in these regions. Spearheaded by the United States, a GCOS Cooperation Mechanism has been established to leverage the resources of developed nations to ensure that dormant GCOS network stations begin to be retrofitted. This will facilitate the collection of valuable surface and upper air data used in climate studies (see, e.g., CCSP Synthesis and Assessment Product 1.1, which is briefly described in the "Climate Variability and Change" chapter.).



Key ocean observations are being made by the United States that are important to both science and society. They include sea level observations, measured using tide gauge stations and satellite observations; ocean carbon sources and sinks; ocean storage and global transport of heat and fresh water; and exchange of heat and fresh water between the ocean and atmosphere. To collect data on these variables, it is necessary to enhance the *in situ* component of the global ocean observing system, including an array of sensors situated across the global oceans. The number of instruments being deployed in the oceanic observing networks is increasing steadily.

The United States has a three-tiered approach to *in situ* land-surface climate observations. In the first tier, a few sites, such as the Atmospheric Radiation Program sites, are heavily instrumented, providing a vast array of high-quality, frequent observations of virtually all key variables measurable from the surface. The second tier, known as the Climate Reference Network (CRN), will include more than 100 sites that make long-term, homogeneous observations of temperature and precipitation (and a few other variables) that can be coupled to long-term historical observations for the detection and attribution of present and future climate change. The third tier, which provides greater spatial coverage than the CRN, is composed of more than 1,000 stations in the existing Historical Climatology Network, selected based on homogeneity and quality standards. This tiered approach provides the spatial coverage necessary to detect regional climate variability and change, as well as the quality controls necessary to ensure that the observations are as bias-free as possible. U.S. contributions to GCOS also include ecosystem, hydrosphere, cryosphere, and atmospheric composition measurements.

Atmospheric Brown Cloud Project. Satellite data reveal thick, polluted layers of haze scattered all over the globe. From populated regions to the once pristine Pacific and Atlantic Oceans, atmospheric brown clouds (visible areas of brown-colored atmosphere) form across the United States, southern Europe, the Amazon, southern Africa, and most of Southeast Asia. Through observations and analyses of atmospheric brown clouds, scientists can learn how dust and pollution particles are transported and what their impacts are on the environment, climate, agricultural cycles, and quality of life. The aim of the Atmospheric Brown Cloud (ABC) project is to integrate air pollution and climate science, using observations (see Figure 25) and impacts modeling and assessment, in order to enhance the scientific basis for informed decisionmaking. ABC is focusing initially on the Indo-Asian and Pacific regions. A primary thrust of ABC is to assess the impact of air pollution and greenhouse gases on the Asian monsoon, which brings much needed rainfall to over 3 billion people in this region.

The ABC project was initiated in 2003 as a long-term multinational effort being carried out under the auspices of the United Nations Environment Programme and the WMO. DOE, NASA, and NOAA support the U.S. component of the project, with

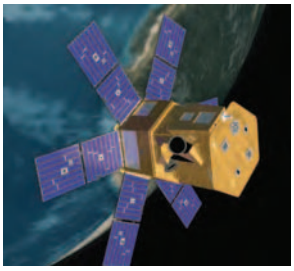
participation by several universities. Global Atmosphere Watch, the atmospheric chemistry component of GCOS, will provide observing stations to be used as platforms for the measurement of aerosols and atmospheric chemical composition. The first new observatory was established in the Republic of the Maldives in October 2004 (see <www-abc-asia.ucsd.edu>). An intensive field observation test period as part of an ABC campaign at Gosan, Korea, was carried out in March 2005.

Polar Observations: ICESat. Polar systems may be especially sensitive to climate change and might provide early indications of climate change. They also interact with climate variability and change through several important feedback processes. Monitoring polar climate and understanding its feedbacks are key priorities described in the *CCSP Strategic Plan*. CCSP supports the creation of systematic data sets for parameters such as sea-ice thickness, extent, and concentration; land-ice and snow-cover mass balance; and surface temperature. Impacts of changes in these and other variables were highlighted in the 2004 Overview report of the Arctic Climate Impact Assessment, *Impacts of a Warming Arctic*.

Figure 25: Atmospheric Brown Cloud (ABC) Network. Map of operational and planned observatories that comprise the Atmospheric Brown Cloud (ABC) network, May 2005. *Credit: V. Ramanathan, Scripps Institution of Oceanography.*

Significant contributions are being made to CCSP's polar observations by NASA's Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003 (see <icesat.gsfc.nasa.gov>). ICESat measures surface elevations of ice and land, vertical distributions of clouds and aerosols, vegetation canopy heights, and other features with unprecedented accuracy and sensitivity. The primary purpose of ICESat has been to acquire time series of ice-sheet elevation changes for determination of the present-day mass balance of the ice sheets, study of associations between observed ice changes and polar climate, and improvement of estimates of the present and future contributions to global sea-level rise. ICESat has achieved remarkable successes with a number of first-of-their-kind observations. Among these are:

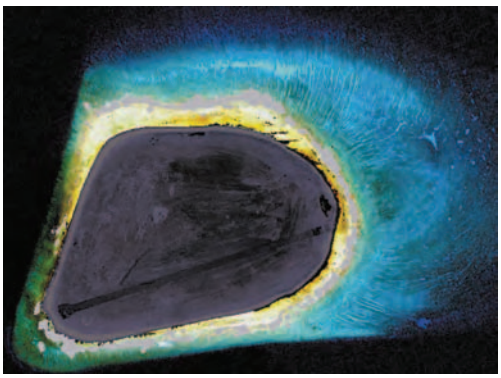
- The most accurate elevation maps to date of the Greenland and Antarctic ice sheets
- Detection of change in the Greenland and Antarctic ice sheets
- Demonstrated ability to characterize detailed topographic features on ice sheets, ice shelves, and ice streams
- Capability of detecting ice-sheet elevation changes as small as centimeters per year
- Pioneering sea-ice thickness mapping (distributions and means)
- Global mapping of heights of clouds and aerosols with unprecedented sensitivity and detail
- Sensing of vegetation canopy heights and density
- Precision mapping of land elevations.



Solar Variability: SORCE. The Sun is the Earth's primary energy source and external driver of climate variability. The Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous measurements. SORCE is now making the first contiguous observations of solar variability across the full solar spectrum, from the far ultraviolet to near-infrared wavelengths. In June 2004, SORCE measured small changes in solar luminosity caused by the transit of Venus, demonstrating unprecedented precision. On 4 November 2004, SORCE documented the largest solar X-ray flare ever recorded and measured associated changes in total solar irradiance. SORCE's operational life is expected to extend across the upcoming 2006-2007 solar minimum, a crucial period for estimating any long-term trend, such as that indicated by indirect measurements of past solar forcing. SORCE is expected to overlap with the Glory mission that will carry forward the total solar irradiance record after 2008, as discussed below. The follow-up to the ultraviolet and other solar spectral measurements of SORCE is not expected until sometime after 2010 when both the total and spectral measurements may become operational as part of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). Continuity of the solar spectral record will require that SORCE last beyond its design life of 5 years.

ARM Mobile Facility. The primary goal of the Atmospheric Radiation Measurement (ARM) Program is to improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models. These efforts have been enhanced by the addition of the ARM mobile facility (AMF) to study cloud and radiation processes in multiple climatic regimes. The AMF can be deployed to sites around the world for durations of 6 to 18 months. Data streams produced by the AMF will be available to the atmospheric community for use in testing and improving parameterizations in global climate models. The first deployment of the AMF is a collaboration between DOE and the DOD Office of Naval Research, which will make observations of marine stratus clouds and cloud-aerosol interactions (see <www.arm.gov/sites/amf.stm>).

Coral Ecosystem Integrated Observing System. Coral reefs are some of the most biologically diverse ecosystems on Earth. They buffer coastal areas from oceanic swells and tides and provide economic benefits through tourism and fisheries. Recent estimates have shown a loss varying from 15 to 25% of the global population of coral reef ecosystems (Buddemeier *et al.*, 2004). While the causes for this degradation may vary, the effects are felt throughout other marine ecosystems and ultimately by the economies of nations dependent on the beauty and bounty of coral reefs to attract tourism and fisheries.



A team of scientists assembled on-site monitoring instruments and satellite remote-sensing data to enhance understanding of the magnitude and complexity of environmental, physical, and biological factors causing coral reef degradation. The integration of monitoring systems is also an effective tool to more fully understand the effects of climate change on coral reef ecosystem health, and to assess the effects of climatic trends on the diversity and abundance of coral reefs through time. The Coral Reef Ecosystem Integrated Observing System (CREIOS) was formed to provide a diverse suite of long-term ecological and environmental observations and information products over a broad range of spatial and temporal scales. The goal is to understand the condition and health of, and processes influencing, coral reef ecosystems, to assist stakeholders in making improved and timely ecosystem-based management decisions to conserve coral reefs. The newly formed CREIOS and NOAA's Coral Reef Watch (see the "Ecosystems" chapter) are at the forefront of integrated research observations spanning domestic and international arenas (see <www.nmfs.hawaii.edu/crd/oceanography.html>).

Data Management and Information

The following are selected data management and information activities supported by CCSP participating agencies.

Integrated Climate Data in the Pacific Islands Region. Efforts to improve climate data integration in the Pacific Islands region are being explored for the purpose of producing more useful end-user-driven products. The Pacific Region Integrated Data Enterprise (PRIDE) is currently underway in Hawaii. This activity efficiently uses existing resources via a newly created NOAA Integrated Environmental Applications Information Center that will be a new-generation data center for the purpose of developing more customer-focused and integrated environmental products. NOAA is partnering with academic and other Federal agencies in the region (e.g., USGS) to provide information on issues related to Pacific islands, including past, current, and future trends in patterns of climate and weather-related extreme events (e.g., tropical cyclones, flooding, drought, and ocean temperature extremes) and their implications for key sectors of the economy such as agriculture, tourism, and fisheries; and options for coastal communities and marine ecosystem managers to adapt to and manage effects of variable and changing environmental conditions (see <apdrc.soest.hawaii.edu/PRIDE>).

Climate Extremes Index. The Climate Extremes Index (CEI) was originally introduced in 1996 as a way to determine whether, and by how much, climate extremes in the United States are changing. The index initially consisted of five separate climate change indicators, combined to yield an overall extremes index summarized on an annual basis. The individual indicators used to investigate possible extremes included mean monthly maximum and minimum temperature, daily precipitation, and the monthly Palmer Drought Severity Index. In recent years, a revised CEI was released that includes a sixth indicator related to extremes in land-falling tropical storm and hurricane wind speed. In addition, the CEI is now evaluated for eight standard periods or seasons, including spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov), winter (Dec-Feb), warm (Apr-Sep), cold (Oct-Mar), hurricane (Jun-Nov), and annual (Jan-Dec). Newly digitized pre-1948 data have also been included to improve spatial coverage without compromising completeness of data. With the addition of near real-time data, the CEI became an operational index in June 2004 and is now updated within the first few weeks after a particular season has ended. Graphs of the most current CEI and the individual indicators that comprise the CEI may be viewed on the CEI web site (see <www.ncdc.noaa.gov/oa/climate/research/cei/cei.html>).

Data Rescue: Climate Database Modernization Program. Through the Climate Database Modernization Program, millions of deteriorating film and paper images were

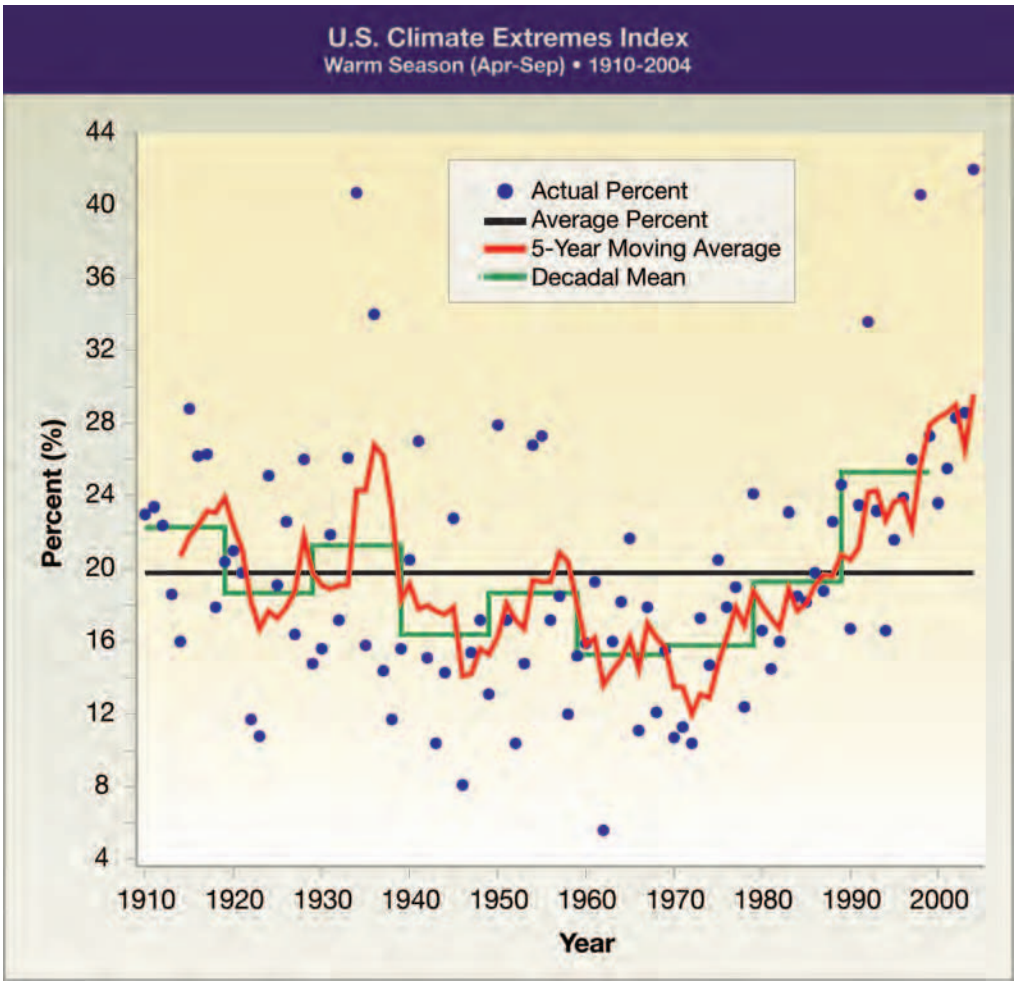


Figure 26: U.S. Climate Extremes Index. U.S. climate extremes index—warm season (April-September), 1910–2004. *Credit: K.L. Gleason, NOAA/ National Climatic Data Center.*

preserved through imaging and manual data entry. The program is a partnership between NOAA and private industry to image and manually enter paper and microfilm records and make them available on the web to members of the climatological research community. Currently there are nearly 42 million images available. Without these data rescue efforts, irreplaceable records of past climate would be lost – records that are vital for maximizing the Nation's ability to assess the nature of past climate variability and change (see <www.ncdc.noaa.gov/oa/climate/cdmp/cdmp.html>).

Improved Access to Radar Data. NOAA significantly improved access to archived Weather Surveillance Radar-88 Doppler data (WSR-88D NEXRAD) and has made these data available for use in retrospective climate studies, particularly in regard to precipitation. With increased bandwidth and advanced information technology, NEXRAD data are now available within hours as opposed to days and weeks (see <www.ncdc.noaa.gov/oa/radar/radarresources.html> and Figure 27).

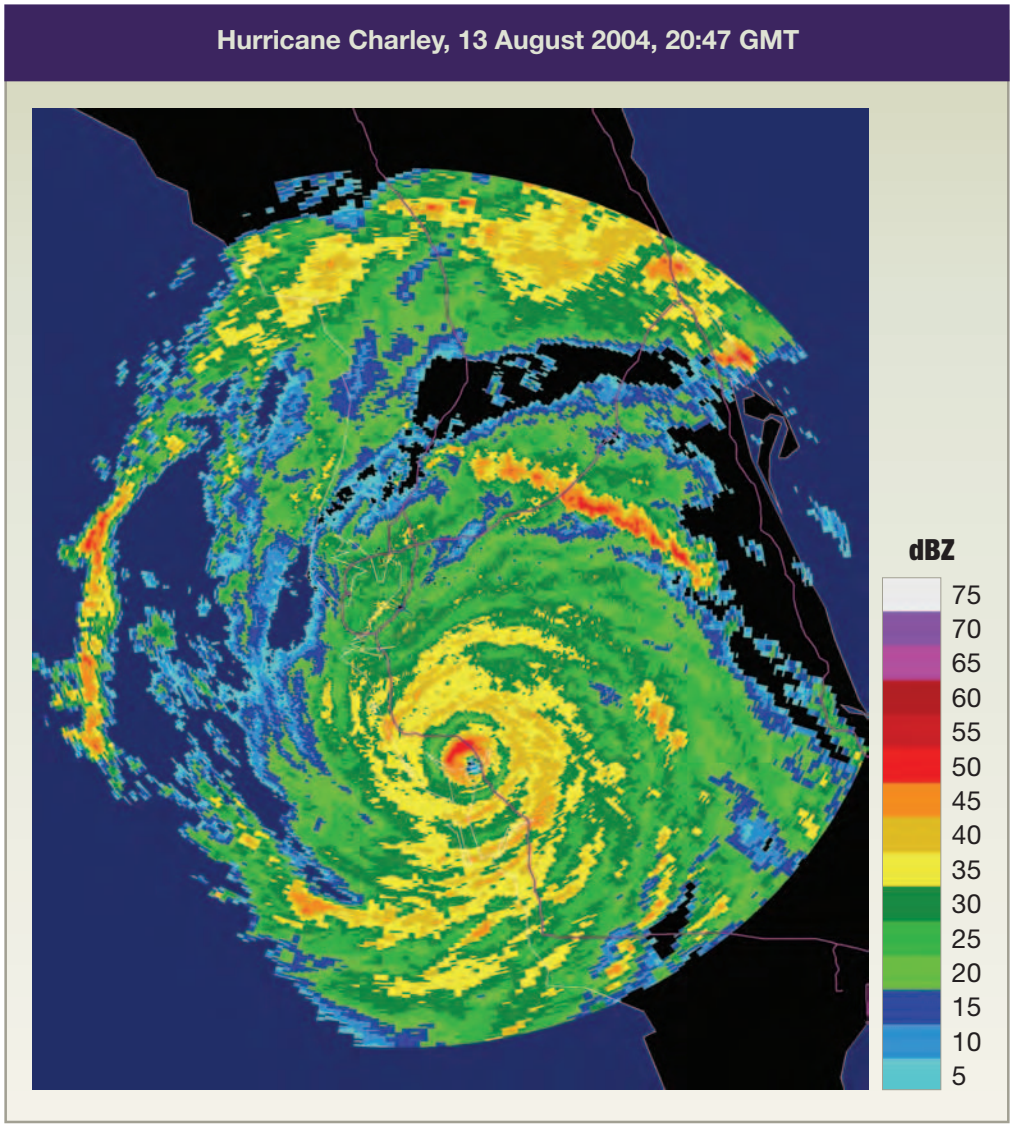


Figure 27: Hurricane Charley, 13 August 2004. Hurricane Charley moving across Florida, August 2004. Image captured by the NOAA/National Weather Service Tampa Bay, Florida, Weather Forecast Office's WSR-88D doppler weather radar. *Credit: NOAA/ National Climatic Data Center*.

REASoN Program. Forty Cooperative Agreement projects that are part of NASA's Earth Science REASoN – Research, Education, and Applications Solutions Network – completed their first year. The REASoN projects are part of NASA's strategy to work with its partners to improve its existing data systems, guide the development and management of future data systems, and focus performance outcomes to further Earth science research objectives. In order to achieve these goals, the REASoN projects are organized to engage the science community and peer review process in the development of higher level science products; use these products to advance Earth system research; develop and demonstrate new technologies for data management and distribution; and contribute to interagency efforts to improve the maintenance and accessibility of data

SYSTEMS FOR DATA MANAGEMENT AND DISTRIBUTION

Cooperative efforts by NASA, NOAA, and other CCSP agencies are moving toward providing an integrated and more easily accessed Earth information system that will effectively preserve, extend, and distribute information about the evolving state of the Earth. A few examples of specific agency efforts are given below. Although each activity has a single lead agency, participation involves many CCSP agencies, as well as State, local, and non-governmental partners.

These activities address Goals 12.3, 12.6, 13.1, 13.2, and 13.4 of the CCSP Strategic Plan.

Earth Observing System Data and Information. NASA's Earth Observing System Data and Information System (EOSDIS) provides convenient mechanisms for locating and accessing products of interest either electronically or via orders for data on media. EOSDIS facilitates collaborative science by providing sets of tools and capabilities such that investigators may provide access to special products (or research products) from their own computing facilities. EOSDIS has an operational EOS Data Gateway (EDG) that provides access to the data holdings at all the Distributed Active Archive Centers (DAACs) and participating data centers from other U.S. and international agencies. Currently, there are14 EDGs around the world that permit users to access Earth science data archives, browse data holdings, select data products, and place data orders.

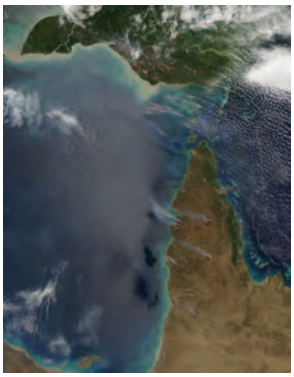
Distributed Active Archive Centers. Eight NASA DAACs representing a wide range of Earth science disciplines comprise the data archival and distribution functions of EOSDIS. The DAACs carry out the responsibilities for processing certain data products from instrument data, archiving and distributing NASA's Earth science data, and providing a full range of user support. There are more than 2,100 distinct data products archived at and distributed from the DAACs. These institutions are custodians of Earth science mission data until the data are moved to long-term archives. They ensure that data will be easily accessible to users. NASA and NOAA have initiated a pilot project to develop a prototype system for testing candidate approaches for moving MODIS data into long-term NOAA archives. This pilot project is part of the evolution of the Comprehensive Large Array-data Stewardship System (CLASS) developed by NOAA. Acting in concert with their users, DAACs provide reliable, robust services to those whose needs may cross traditional discipline boundaries, while continuing to support the particular needs of their respective discipline communities. The DAACs are currently serving a broad and growing user community at an increasing rate.

Global Change Master Directory. The Global Change Master Directory (GCMD) is an extensive directory of descriptive and spatial information about data sets relevant to global change research. The GCMD provides a comprehensive resource where a researcher, student, or interested individual can access sources of Earth science data and related tools/services. At present the GCMD database contains over 17,200 metadata descriptions of data sets from more than 1,200 government agencies, research institutions, archives, and universities worldwide; updates are made at the rate of 900 descriptions per month. The GCMD contains descriptions of data sets covering all disciplines that produce and use data to help us understand our changing planet. Although much research is focused on climate change, the GCMD includes metadata from disciplines including atmospheric science, oceanography, ecology, geology, hydrology, and human dimensions of climate change. This interdisciplinary approach is aimed at researchers exploring the interconnections and interrelations of multidisciplinary global change variables (e.g., how climate change may impact human health). The GCMD has made it easier for such data users to locate the information they desire. A portal has been created in support of GEOSS. The professional relationship between the system developers and the scientists has yielded an environment where the developers respond to the needs of potential users.

Scientific Data Stewardship. Scientific Data Stewardship (SDS) is a new paradigm in data management at NOAA, consisting of an integrated suite of functions to preserve and exploit the full scientific value of environmental data. These functions are careful monitoring of observing system performance for long-term applications; generation of authoritative long-term records from multiple observing platforms; assessment of the state of the atmospheric, oceanic, land, cryospheric, and space environments; and proper archival of and timely access to data and metadata. In this process, SDS will correct many data problems identified by the scientific community and permit more significant applications to economic and social issues to help fulfill NOAA's environmental stewardship mission. Successful implementation of SDS will ensure that the Nation's environmental data (initially from NOAA and NASA) are of maximum use to the Nation now and in the future.

National Data Centers. NOAA's National Data Centers and their worldwide clientele of customers look to CLASS as the primary NOAA information technology infrastructure project in which all of its current and future large-array environmental data sets will reside. CLASS builds upon systems already in place to implement an integrated, national environmental data access and archive system to support a comprehensive data management strategy. CLASS provides permanent, secure storage and safe, efficient access between Data Centers and customers. CLASS is able to ingest, archive, and provide access to data produced from large-array data sources, such as existing and future environmental satellite systems. This includes the next generation of NOAA polar-orbiting satellites, which will provide a significant increase in observing capability, and also a significant increase in data rates. Recent accomplishments include implementation of free Internet-based customer access to NOAA geostationary satellite data and the start of the NPOESS Preparatory Project to ensure that CLASS is ready for the launch of this next-generation polar-orbiting satellite mission in late 2006.

and information systems. A list of ongoing activities under this program can be found at <research.hq.nasa.gov/code_y/nra/current/CAN-02-OES-01/winners.html>.)



Highlights of Plans for FY 2006 and Beyond

CCSP will support the development and implementation of integrated systems for observations and monitoring of climate and global change, and associated data management and information systems. Selected key planned activities for FY 2006 and beyond follow.

Global Climate Observing System. The first element of GCOS that is expected to be completed in 2005 is the global drifting buoy array, a group of 1,250 drifting buoys measuring sea surface temperature and other variables. In FY 2006, the full complement of 3,000 Argo floating buoys will be deployed. Sea-level measurements, provided by the Absolute Altimeter Calibration Station, will transition from NASA to NOAA funding. Continued upgrading of the Global Sea-Level Observing System tide gauge network from 43 to 170 stations is planned for the next few years. Ocean carbon inventory surveys funded by both NOAA and NSF in a 10-year repeat survey cycle will help determine the uptake of anthropogenic carbon by the oceans. Plans for enhancement of the global Tropical Atmosphere Ocean network include advances into the Indian Ocean, with three moorings in the Indian Ocean in 2005 followed by two more in both FY 2006 and 2007. This will enhance the tropical networks currently monitoring above-surface, surface, and subsurface conditions in the Pacific and Atlantic Oceans. Work will continue in FY 2006 to reestablish GCOS Upper Air Network sites in key developing country locations as determined by the GCOS atmospheric science community.

Ocean analysis activities will be initiated in FY 2006 to advance data assimilation and analysis subsystems. Long-range planning includes building the number of ocean observing networks with a focus on the polar regions, especially the Arctic, for impacts of climate change; ocean circulation changes to monitor for possible indications of abrupt climate change; and ocean-atmosphere exchange of heat and water, particularly in support of drought early warning and diagnostics.

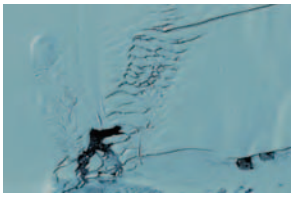
These activities will address Goals 12.3 and 12.5 of the CCSP Strategic Plan.

Atmospheric Brown Cloud Sites. The fundamental goal of ABC is to integrate air pollution and climate science to assess the impacts on the environment and society. Since Asia is the source of more than 50% of sulfur dioxide and black carbon emissions, ABC's first focus is on the Asian region. Ten new observatories will be established in the Indo-Asia-Pacific region over the next 3 to 5 years. These will be combined with

three existing observatories in the region. Plans are in place to bring the second ABC super site at Gosan, Korea, into operation.

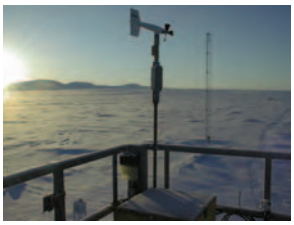
ABC will generate a database for estimating the radiative forcing due to aerosols, including black carbon and aerosol-cloud interactions. With respect to impact assessment, ABC will estimate the effects of aerosol and greenhouse gas radiative forcing on climate and hydrological cycles and the resulting impacts on agriculture and water budgets. As noted previously, ABC is coordinating an integrated regional and global modeling effort. The ABC observations, integrated with NOAA and NASA satellite observations, will provide the input (e.g., climate forcing at monthly time scales and regional spatial scales) for these models. In turn, these models will provide links between observations and policy by assessing the possible impacts of past emissions and "business-as-usual" emissions scenarios.

These activities will address Goals 12.2, 12.4, and 12.5 of the CCSP Strategic Plan.



Polar Region Observations: International Polar Year. Polar climate observations will continue to be a CCSP focus as preparations are made for the International Polar Year (IPY), which will begin in 2007. The IPY coincides with the 50th anniversary of the International Geophysical Year, which in 1957 initiated the systematic observation of key climate variables such as atmospheric CO_2. For further information on the IPY, see <dels.nas.edu/us-ipy>.

The United States plans to increase its efforts on observations of the Arctic atmosphere, sea ice, and ocean. Working with Canada, NOAA will deploy an atmospheric observatory in northeastern Canada to mirror current activities in Barrow, Alaska. Together, these observatories will provide an improved high-resolution characterization of clouds and aerosols, and of incoming and outgoing radiation. A wealth of satellite data will also be available for polar regions in 2007. Two satellites to be launched early in FY 2006, CALIPSO and Cloudsat, will use lidar and radar to provide three-dimensional distributions of aerosols and layered clouds. Data from these surface- and space-based observatories will provide high-quality records needed to detect potential future climate change. Calibration and validation field programs utilizing airborne and balloon-borne sensors associated with these satellite missions and other programs will greatly aid in the intensive characterization of the Arctic.



Additional effort will be made to detect changes in sea ice through deployment of buoys to measure sea-ice properties directly, and also through new satellite sensors (see, e.g., ICESat description above) whose calibration can be enhanced by the availability of an increased set of buoy data. Changes in the temperature and salinity structure of the ocean beneath sea ice could be a critical indicator of changes in the climate system, and new efforts will be made to gather such data. The Bering, Chukchi, and Beaufort Seas off Alaska are home to many valuable living resources, including fish, marine mammals, and birds, that are affected by ocean currents and the seasonal progression

of sea ice. There is evidence that these areas are warming and that the annual period of ice cover is diminishing. The biotic response to these physical changes will be studied through enhanced observations by automated systems and ship-based activities.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Earth System Science Pathfinder Program. NASA's Earth System Science Pathfinder (ESSP) program is the primary source of exploratory missions to complement the EOS satellites Terra, Aqua, and Aura. The ESSP program consists of smaller missions developed and implemented on a faster schedule, proposed by the scientific community to address specific research questions. The first ESSP mission, the Gravity Recovery and Climate Experiment, was launched in March 2002. A second launch, planned for fall 2005, will deploy two more ESSP satellites, CloudSat and CALIPSO, as mentioned in the previous subsection. After initial testing and quality control, science data from these key missions will be available beginning in 2006.

CloudSat, a joint mission involving NASA, the U.S. Air Force, and the Canadian Space Agency, is designed to measure cloud properties that are critical for understanding clouds' effects on both weather and climate. These cloud properties are not obtainable from current satellite measurement systems. The mission's primary science goal is to furnish data needed to evaluate and improve the way clouds are parameterized in global models, thereby contributing to better predictions of clouds and to a better

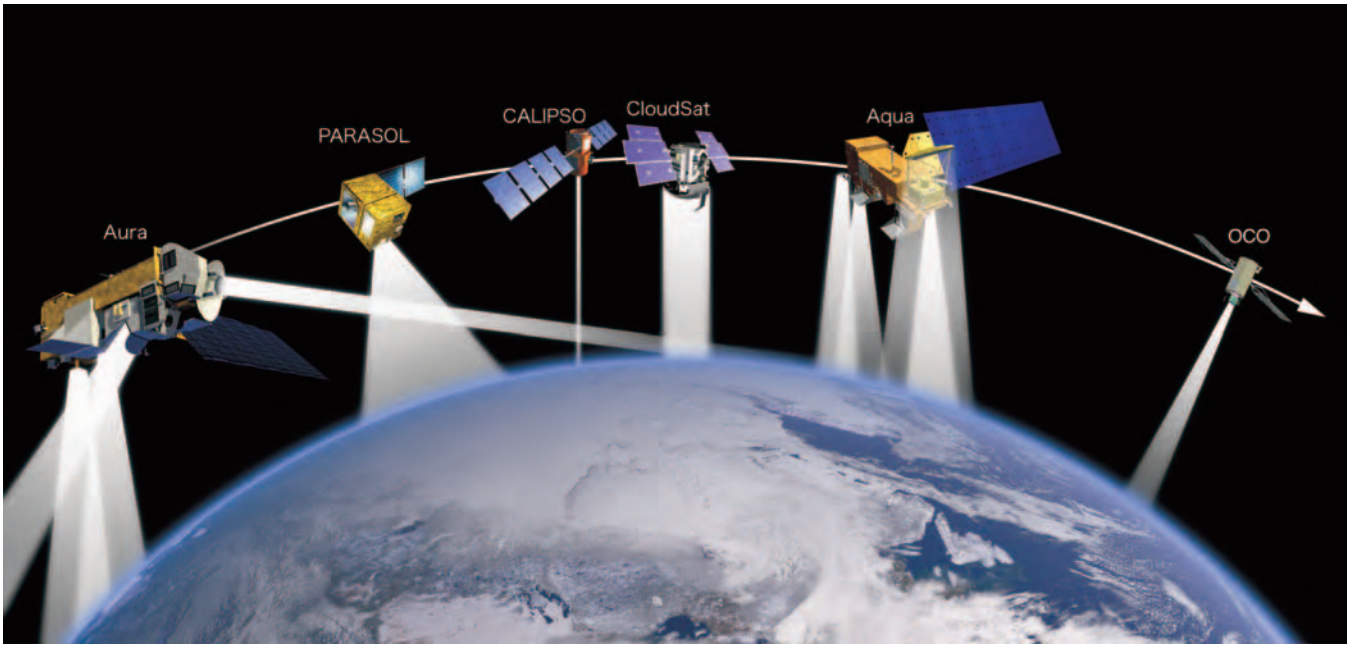
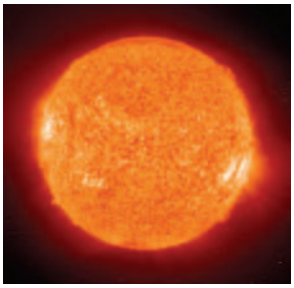


Figure 28: The "A-Train". This figure illustrates the constellation of satellites known as the "A Train," which will make nearly contiguous observations of many facets of the Earth system. *Credit: NASA*.

understanding of poorly understood cloud-climate feedbacks. CloudSat's key observations are the vertical profiles of cloud liquid-water and ice-water content and related physical and radiative properties. It will fly in tight formation with the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. CALIPSO is being developed to provide new information about the effects of thin clouds and aerosols on changes in the Earth's climate. Global measurements of the three-dimensional distributions of aerosols and clouds will provide scientists with a more comprehensive data set that is essential for a better understanding of the Earth's climate forcings and feedbacks. The CALIPSO mission is implemented in collaboration with the French space agency, Centre National d'Etudes Spatiales. CloudSat and CALIPSO will follow behind the Aqua satellite as part of the multi-satellite formation termed the "A-train" (see Figure 28). Also included in the "A-train" satellite formation will be the PARASOL mission to measure cloud and aerosol properties using polarization of reflected sunlight. The combination of these data with coincident measurements from Aqua and Aura will provide a rich source of information that can be used to assess the role of clouds in both weather and climate.

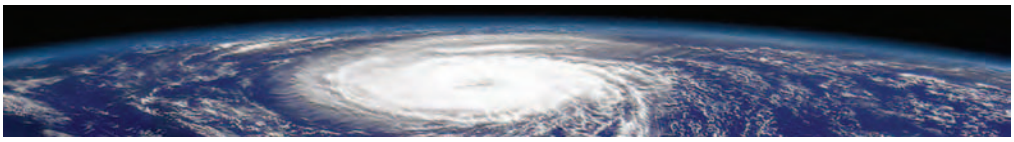
These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.



Solar Variability: Glory. The Glory mission will continue to be developed in FY 2006, and is planned for 2008 launch. It will carry a Total Irradiance Monitor (TIM) based on the SORCE TIM design, with the same high-precision phase-sensitive detection capability. Glory will also carry an Aerosol Polarimeter Sensor (APS), which will improve our ability to distinguish among aerosol types by measuring the polarization state of reflected sunlight. Both TIM and APS will provide key measurements beginning in 2007, the minimum of solar cycle 24. This less active portion of the 11-year solar cycle is especially crucial in estimating any long-term trends in solar output – a key to understanding the 20th-century context of global change, as the Sun is the single entirely "external" forcing of the climate system that is unaffected by climate change itself. Glory is described at <www.esa.ssc.nasa.gov/m2m/mission_report.aspx?mission_id=233>. The International Heliophysical Year is summarized at <ihy.gsfc.nasa.gov>.)

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Global Precipitation Measurement Mission. Motivated by the successes of the TRMM satellite and recognizing the need for a more comprehensive global precipitation measuring program, NASA and the Japan Aerospace Exploration Agency conceived a new Global Precipitation Measurement (GPM) Mission. A fundamental scientific goal of the GPM Mission is to make substantial improvements in global precipitation observations, especially in terms of measurement accuracy, sampling frequency, spatial resolution, and coverage, thus extending TRMM's rainfall time series. To achieve this



goal, the mission will consist of a constellation of low-Earth-orbiting satellites carrying various passive and active microwave measuring instruments. The GPM Mission will be used to address important issues central to improving the predictions of climate, weather, and hydrometeorological processes, and also to stimulate operational forecasting and to underwrite an effective public outreach and education program, including near-real-time dissemination of televised regional and global rainfall maps. Assessment of how natural and anthropogenic aerosols affect precipitation variability (therefore the water cycle) is a complex and important problem. The capability to monitor the diurnal cycle of rainfall globally with GPM is expected to enable significantly improved understanding of the links between aerosols, climate variability, weather changes, hydrometeorological anomalies, and small-scale cloud macrophysics and microphysics.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

Orbiting Carbon Observatory. The Orbiting Carbon Observatory (OCO) is a new mission, being prepared to launch in 2008, to provide the first space-based measurements of atmospheric CO_2 (total column) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability. Analyses of OCO data will regularly produce precise global maps of CO_2 in the Earth's atmosphere that will enable more reliable projections of future changes in the abundance and distribution of CO_2 in the atmosphere and the effect that these changes may have on the Earth's climate.

These activities will address Goals 12.2 and 12.5 of the CCSP Strategic Plan.

Sea Surface Temperature. Both short-term numerical weather prediction and longer term climate change detection require sea surface temperature (SST) measurements made frequently, on a global scale, and at fine spatial resolution. Currently there are many different satellite-derived SST data sets available with a number of options in terms of product content, coverage, spatial resolution, timeliness, format, and accuracy. Realizing that the existing SST data products are less than ideal for numerical weather prediction and regional-scale climate change detection, the international Global Ocean Data Assimilation Experiment steering committee initiated a pilot project in 2005 to develop an operational demonstration system that will deliver a new generation of global-coverage high-resolution (better than 10-km and collected approximately every 6 hours) SST data products. The data products will be derived by combining readily available but complementary satellite and *in situ* observations in real-time to improve

spatial coverage, temporal resolution, cross-sensor calibration stability, and SST product accuracy.

These activities will address Goals 12.1 and 12.5 of the CCSP Strategic Plan.

African Monsoon Multidisciplinary Analysis. African Monsoon Multidisciplinary Analysis (AMMA) is an international project to improve our knowledge and understanding of the West African monsoon (WAM) and its variability, with an emphasis on daily-to-interannual time scales. AMMA is motivated by an interest in fundamental scientific issues and by the societal need for improved prediction of the WAM and its impacts on West African nations. As noted in the "Climate Variability and Change" chapter, U.S. involvement in AMMA will focus on climate, weather, and related aerosol issues associated with the African monsoon regions. A multidisciplinary field program is planned, combining long-term monitoring over several seasons with intensive observations in the summer of 2006. The field measurements will be used to test and improve predictive models for the environment and climate of Africa, and for the impact of the African monsoon on the global environment. U.S. participation in AMMA may include ship, aircraft, and oceanographic sensors proposed for support from multiple CCSP agencies. The ARM Mobile Facility will be deployed in 2006.

These activities will address Goals 12.2 and 12.3 of the CCSP Strategic Plan.

USGEO Near-Term Opportunity. USGEO was established in March 2005 as a standing subcommittee of the National Science and Technology Council Committee on Environmental and Natural Resources to replace the ad hoc IWGEO. USGEO has outlined a process for the development of a modern information management system, based on Federal Enterprise Architecture principles. The process follows contemporary commercial and academic practices for integrating distributed resources within a virtual organization framework based on a service-based architecture. It uses existing data management planning as its foundation, and relies heavily on an articulation of how data are used to drive the system design. USGEO is developing specific guidance to advance existing agency efforts that address the six "Near-Term Opportunities" outlined in the *USGEO Strategic Plan*: disaster warning, global land cover, sea level, drought, air quality, and enhanced data management (see <iwgeo.ssc.nasa.gov>).

These activities will address Goals 12.6 and 13.3 of the CCSP Strategic Plan.

OBSERVING AND MONITORING CHAPTER REFERENCE

1) **Buddemeier**, R.W., J.A. Kleypas, and R. Aronson, 2004: *Coral Reefs and Global Climate Change. Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems*. Prepared for the Pew Center for Global Climate Change, 42 pp. Available at <www.pewclimate.org/global-warming-in-depth/all_reports/coral_reefs/index.cfm>.

9 Communications

The *CCSP Strategic Plan* calls upon CCSP agencies and departments to coordinate their communications efforts while focusing on two goals:

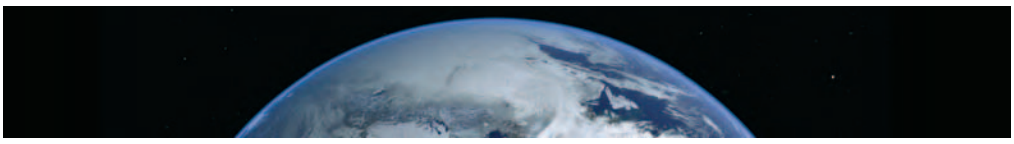
- Disseminate the results of CCSP activities credibly and effectively
- Make CCSP science findings and products easily available to a diverse set of audiences.

In order to accomplish these objectives, the *CCSP Strategic Plan* states that CCSP will formalize a working group to develop and help implement an interagency communications plan for the program. During FY 2004, the Communications Interagency Working Group (CIWG) was formally established. The CIWG completed a 1-year implementation plan that the CCSP Principals approved in January 2005. The implementation plan will guide CCSP's coordinated interagency communications efforts for the balance of FY 2005 and early FY 2006.

Under the implementation plan, the CIWG will help produce:

- Products on climate change science fundamentals such as "Frequently Asked Questions" and educational fact sheets
- A series of information pieces about CCSP and its activities
- Fact sheets and other outreach materials and activities on quarterly featured topics that focus on cross-agency research efforts
- Ancillary outreach material to accompany research products issued by CCSP working groups.

The Climate Change Science Program Office (CCSPO), funded and supervised by the agencies and departments participating in CCSP, supports the program's communications goals, along with members of the CIWG. CCSPO assists the CIWG, coordinates preparation of the annual *Our Changing Planet* report to Congress as well as other reports, and is responsible for managing the program's interagency web sites.



Highlights of Recent Interagency Communications Activity

Listed below are highlights of recent communication activities coordinated at the interagency level.

- Published and distributed *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005*. CCSP produced 6,000 hardcopies of the report, issued a digital version on CD-ROM, and distributed 1,000 copies of the CD at the Tenth Session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP-10).
- Added new material to CCSP's publicly accessible web sites, including:
  - The FY 2004-2005 edition of *Our Changing Planet*
  - Guidelines for producing CCSP synthesis and assessment products
  - Prospectuses for several synthesis and assessment products, which include background information on the planned report and a detailed roadmap that will be followed in producing it.
- Ensured early and ongoing review of synthesis and assessment products by stakeholder communities.
- Facilitated stakeholder participation in the U.S. Government review of draft documents of the Intergovernmental Panel on Climate Change (IPCC).
- Facilitated observations and research that led to the production of a large body of publications in the peer-reviewed literature and presentations at scientific conferences.
- Facilitated the initiation of numerous scientific and stakeholder workshops, including an Ecosystems workshop and multiple workshops providing input to the CCSP synthesis and assessment activities.
- Engaged media to respond to queries and promote awareness of the program's functions and goals and activities to the general, non-scientific public, as well as policymakers and Congress.
- Managed and improved CCSP web sites. Traffic to CCSP's two main web sites grew rapidly to an average of 5,000 visits per day by the end of FY 2004. CCSPO also has improved integration among the interagency public web sites and improved web services to working groups.
- Assumed responsibility for the Global Change Research Information Office


Overview of the U.S. Climate Change Science Program

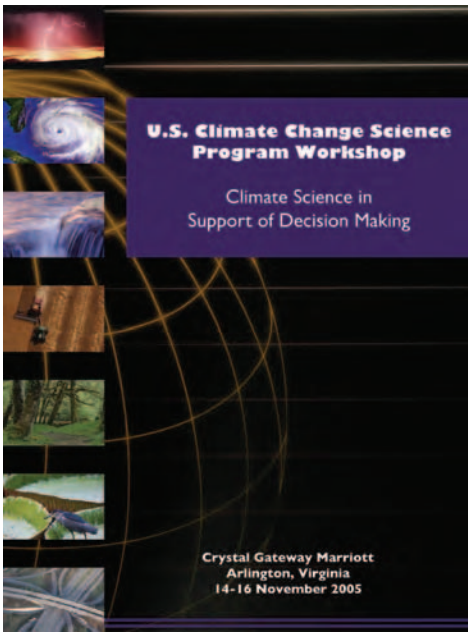
(GCRIO), which was managed previously by the Center for International Earth Science Information Network at Columbia University. Mandated by the Global Change Research Act of 1990, the purpose of the office is to "disseminate to foreign governments, businesses, and institutions, as well as the citizens of foreign countries, scientific research information available in the United States which would be useful in preventing, mitigating, or adapting to the effects of global change." GCRIO includes a major web site (see <www.gcrio.org>), with two important features:

  - *GCRIO Online Catalog* for requesting reports and CDs (see <www.gcrio.org/orders>), which CCSPO upgraded, resulting in a rapid increase in the number of orders received and items shipped
  - *Ask Dr. Global Change* (see <www.gcrio.org/ask-doctor.html>), which answers global change questions submitted by web site visitors, with selected answers also posted to a publicly accessible online archive of answers.
- Established and managed the Climate Change Technology Program (CCTP) web site (see <www.climatetechnology.gov>). CCSPO also provides additional support services to CCTP, including development and management of password-protected web sites and publications support.

Highlights of CCSP Interagency Communications Plans for FY 2006

Listed below are some of the communications activities coordinated at the interagency level and planned for FY 2006:

- Ensure early and ongoing review of new synthesis and assessment products by stakeholder communities.
- Convene a CCSP workshop, "Climate Science in Support of Decision Making," for scientists and stakeholders in November 2005.
- Prepare, publish, and disseminate the FY 2006 and FY 2007 editions of *Our Changing Planet*.
- Facilitate stakeholder participation in the U.S. Government review of draft documents of the IPCC.
- Define and launch one or more pilot projects, as outlined in the *CCSP Strategic Plan*.



- Continue to improve and expand websites:
  - Prepare and post new web content
  - Improve web site usability and accessibility
  - Enhance integration between agency and interagency web sites
  - Expand web services to CCSP working groups.

10 International Research and Cooperation

International coordination and cooperation are essential to improve understanding of climate variability and change. An international approach to research is required because of the global scope of the climate system as well as limitations in the scientific capacity and financial resources of any one country.

The United States continues to advocate the development and maintenance of an informal international framework to enhance international cooperation within which climate change science, including research and observational programs, may be planned and implemented effectively. The goals of U.S. efforts to promote international cooperation in support of CCSP are to:

- Actively promote and encourage cooperation between U.S. scientists and scientific institutions and agencies and their counterparts around the globe so that they can aggregate the scientific and financial resources necessary to undertake research on global change at all relevant scales, including both regional and global.
- Expand observing systems in order to provide global observational coverage of variability and change in the atmosphere, oceans, and on land, especially as needed to underpin the research effort.
- Ensure that the data collected are of the highest quality possible and suitable for both research and forecasting, and that these data are exchanged and archived on a timely and effective basis among all interested scientists and end users.
- Support development of scientific capabilities and the application of results in developing countries in order to promote the fullest possible participation by scientists and scientific institutions in these countries in research, observational, and data management efforts.

These goals draw directly on the needs identified by the U.S. scientific community and are described in the *CCSP Strategic Plan*.

CCSP participates in and provides input to major international scientific and related organizations on behalf of the U.S. Government and scientific community. It does so

in part through its working groups, including the Interagency Working Group on International Research and Cooperation. In addition to promoting and encouraging participation of U.S. scientists and scientific institutions in international climate science, CCSP also shares in multilateral international support to maintain the central coordinating infrastructure of major international research programs and international activities that complement CCSP and U.S. Government goals in climate science.

In FY 2004 and 2005, the United States sought to encourage international cooperation in the development of observing systems through its continued participation in the Global Earth Observing System of Systems (GEOSS) and other activities such as the Global Climate Observing System (GCOS).

The United States also cooperated with its partners in a number of international scientific assessment and decision-support activities such as the Intergovernmental Panel on Climate Change (IPCC), the Arctic Climate Impact Assessment, and other application-related programs such as the International Research Institute for Climate Prediction.

The United States also continued its support for the major international global change research programs, including the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the International Geosphere-Biosphere Programme (IGBP), and DIVERSITAS. These programs are now coordinating their activities through the Earth System Science Partnership (ESSP). The SysTem for Analysis, Research, and Training receives strong U.S. support for its activities to promote outreach and capacity building that supports the WCRP, IGBP, IHDP, and DIVERSITAS. The United States also continued its support of international regional global change research networks such as the Inter-American Institute for Global Change Research, and the Asia-Pacific Network for Global Change Research. With cooperation from ESSP, the United States has provided support for a workshop to explore needs and opportunities for more formal cooperation in global change research in Africa.

Finally, in FY 2004 and 2005, the United States, through CCSP agencies, supported a variety of climate-related international research programs that advanced several Presidential initiatives and the suite of 15 climate change bilateral agreements coordinated by the U.S. Department of State.

Highlights of these and other key international activities led by or participated in by CCSP are outlined below.

International Cooperation in Observing Systems

Global Earth Observing System of Systems. On 31 July 2003 in Washington, D.C., 33 nations plus the European Commission adopted a declaration that signifies political commitment to move toward development of a comprehensive, coordinated, and sustained Earth observation system(s). The Earth Observation Summit attracted a distinguished group of government dignitaries from around the world who are committed to significantly advancing the collective ability to gather Earth observation data.

The Summit participants affirmed the need for timely, high-quality, long-term, global information as a basis for sound decisionmaking. In order to monitor continuously the state of the Earth, to increase understanding of dynamic Earth processes, to enhance prediction of the Earth system, and to further implement environmental treaty obligations, participants recognized the need to support the creation of a comprehensive, coordinated, and sustained Earth observing system of systems.

To further this goal, the Summit participants launched the intergovernmental ad hoc Group on Earth Observations (GEO) to develop a 10-Year Implementation Plan. The group, co-chaired by the United States, the European Commission, Japan, and South Africa, currently comprises more than 50 countries and more than 30 international organizations. While a GEOSS will benefit the climate community, it will also address a wide range of other priority applications – for example, management of agriculture, biodiversity, disasters, ecosystems, energy resources, health, water, and weather-related risks.

Ministers met for the Second Earth Observation Summit in Tokyo, Japan, on 25 April 2004, where they adopted the Framework Document for a 10-Year Implementation Plan for this initiative. The plan was adopted by ministers at the Third Earth Observation Summit, hosted by the European Commission on 16 February 2005. A new GEO Secretariat, hosted by the World Meteorological Organization, has been established in Geneva.

Global Climate Observing System. GCOS was established in 1992 to ensure that the observations necessary to address climate-related issues are defined, obtained, and made available to all potential users. GCOS is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU). GCOS is working closely with GEO in the development of its implementation and work plans for the climate component of the GEOSS.

GCOS coordinates and facilitates the taking of required observations by national or international organizations in support of their own requirements as well as of

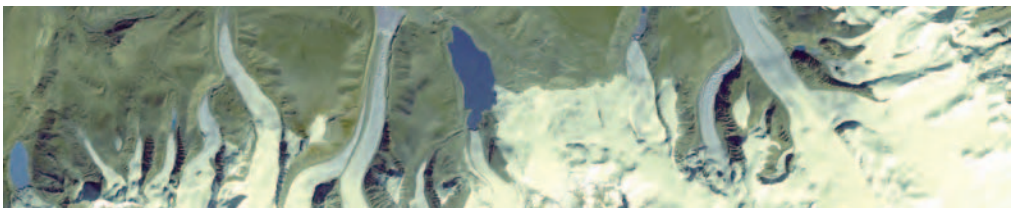
common goals. It provides an operational framework for integrating, and enhancing *in situ* and space-based observational systems of participating countries and organizations into a comprehensive system focused on the requirements for climate issues.

GCOS builds upon, and works in partnership with, other existing and developing observing systems such as the Global Ocean Observing System, the Global Terrestrial Observing System (GTOS), and the Global Observing System and Global Atmosphere Watch of the WMO. It draws upon proven networks established under research programs such as the WCRP and the IGBP.

GCOS also works very closely with the United Nations Framework Convention on Climate Change (UNFCCC) and its Conference of the Parties (COP), for whom it has developed an adequacy assessment and the GCOS Implementation Plan for defining and obtaining systematic observations of the climate system to meet the needs of the UNFCCC. This has led to a number of COP decisions and recommendations to the Parties in direct support of climate observation. U.S. GCOS activities and interactions with the GCOS Secretariat are coordinated by a U.S. GCOS Program Manager who works at NOAA's National Climatic Data Center.

The Global Observations of Forest Cover and Land Cover Dynamics (GOFC-GOLD) Project. GOFC-GOLD is an international project with participation from USGS, NOAA, NASA, and several U.S. universities working in an internationally coordinated way to provide ongoing space-based and *in situ* observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget.

The GTOS GOFC-GOLD project regularly conducts workshops for enhancing regional science networks and for observation coordination and data capacity building. In 2004, GOFC-GOLD, the Committee on Earth Observation Satellites Land Product Validation Workshop, and regional GOFC-GOLD data capacity building workshops were held in northern Eurasia, southern Africa, Southeast Asia, and South America, as well as an Implementation Team meeting on Land Cover. The GOFC Secretariat is managed by the Canadian Forest Service supported by the Canadian Space Agency. The UN Food and Agriculture Organization GTOS Secretariat maintains the GOFC-GOLD web site (see <www.fao.org/gtos/gofc-gold/2005_e.html>), which provides updates on project activities and forthcoming events.

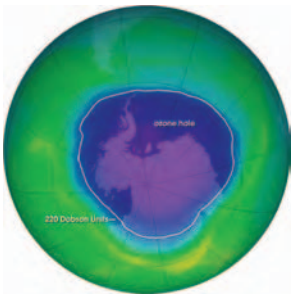


Selected International Assessments and Decision-Support Programs

Intergovernmental Panel on Climate Change. The U.S. Government has played an active role in the IPCC process since its inception, and continues to do so. The United States chairs IPCC's Working Group I (which focuses on the physical basis of climate change) and provides support for its Technical Support Unit. In 2004, CCSP coordinated the nomination and review process for authors of the upcoming IPCC *Fourth Assessment Report*, set to be published in 2007, for the U.S. Government. Three panels, comprised of representatives from all CCSP agencies, reviewed over 400 nominations of U.S. scientists. This nomination and review period resulted in a large and strong group of U.S. nominees to the IPCC.

In FY 2005, the IPCC approved comprehensive assessments on two focused issues relating to climate change. In July 2005, it approved a *Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Relating to Hydrocarbons and Perfluorocarbons*. The report covers scientific aspects of ozone-depleting substances and their substitutes as they pertain to radiative forcing, as well as issues involved in addressing atmospheric emissions of these classes of substances. In September 2005, it approved a *Special Report on Carbon Dioxide Capture and Storage*. Both reports involved strong participation from U.S. scientists and technical experts. CCSP coordinated the U.S. Government reviews of the first of these reports, and the Climate Change Technology Program (CCTP) coordinated review of the latter report.

CCSP supports participation of experts to serve as Coordinating Lead Authors, Lead Authors, and Review Editors of the reports and to participate in workshops that contribute to the IPCC process. At present, 116 U.S. scientists serve as authors on IPCC reports under preparation, and 15 as Review Editors. CCSP also coordinates the U.S. reviews of draft reports at the request of the Department of State.

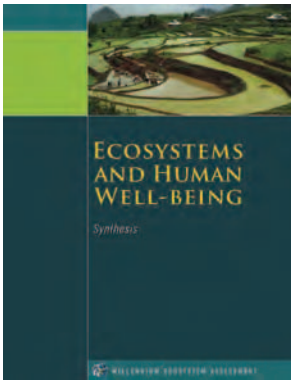


Scientific Assessment of Ozone Layer Depletion. The international state-of-scientific understanding assessment reports regarding the ozone layer are produced every 4 years in accordance with the U.N. Montreal Protocol, to which the United States and over 180 other nations are signatories. The forthcoming *Scientific Assessment of Ozone Depletion: 2006* is in preparation and will be published in early 2007.

The report will describe the current status of understanding regarding ozone-depleting substances in the atmosphere, polar and global ozone observations, climate-ozone connections, expectations for future halocarbon levels and the ozone layer, and observed/future surface UV radiation. The report plays a particularly unique role in communicating scientific understanding to international decisionmakers regarding ozone-depleting substances and the protection of the ozone layer.

The ozone assessment is produced under the auspices of the WMO and UNEP. The United States has played a leading role in the international ozone assessments since their inception. Currently, U.S. scientists serve as two of the three co-chairs of the Montreal Protocol Scientific Assessment Panel and coordinating editor of the 2006 report. U.S. scientists are also prominent among the lead authors, co-authors, and reviewers.

Arctic Climate Impact Assessment. November 2004 marked the release of the 140-page synthesis report of the Arctic Climate Impact Assessment, *Impacts of a Warming Arctic*. This document can be downloaded from <amap.no/acia/> or ordered from Cambridge University Press. The individual science chapters of the full report have been released at <www.acia.uaf.edu/pages/scientific.html>. The full underlying document, scheduled for publication at the end of 2005, is the most comprehensive document to date addressing the state of the Arctic climate. It will serve the scientific and policy communities as an important reference on Arctic climate, its changes, and potential impacts and will also be available from Cambridge University Press. The U.S. Government will continue to support, and U.S. scientists will continue to participate in, activities with other pan-Arctic nations through the Arctic Council and other organizations.



Millennium Ecosystem Assessment. The Millennium Ecosystem Assessment (MA) is designed to meet the needs of decisionmakers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes. The MA identifies climate change as one of the key issues affecting current and projected future ecosystem change. The MA focuses on ecosystem services (the benefits people obtain from ecosystems), how changes in ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and response options that might be adopted at local, national, or global scales to improve ecosystem management and thereby contribute to human well-being and poverty alleviation. The MA is a multi-scale assessment, consisting of interlinked assessments undertaken at local, watershed, national, regional, and global scales. More than 1,300 authors, many from the United States, have been involved in four expert working groups preparing the global assessment, and hundreds more in the sub-global assessments. The MA Synthesis Report was released in March 2005, with the MA's other global and sub-global assessment reports scheduled for publication in 2005 and 2006.

The International Research Institute for Climate Prediction. The International Research Institute for Climate Prediction (IRI) works within an expanding network of partnerships to address, and when possible mitigate, the frequently damaging

effects of climate variability on societies in developing countries. This network draws on the respective strengths of local, national, multinational, research, academic, governmental, and non-governmental institutions. It provides an effective means for the directed transfer of technology and the concentration of relevant information and ideas from many sectors, disciplines, and regions.

Over the last 9 years, IRI has continued to develop the capacity to use climate forecasting to anticipate, understand, and manage a growing number of the impacts of climate variability. Their case studies, tools, and models have been applied to climate-influenced problems that range from reservoir management in the Philippines to malaria in Southern Africa and agriculture management in Uruguay. Its success has depended on the mutual sharing of knowledge and capacity with local organizations and individuals, who understand local conditions, needs, and opportunities and are best equipped to implement local solutions.

The IRI's global network of partners allows them to draw from a broad range of relevant disciplines as well as from concrete experiences of project success and failure from around the world. Their understanding of the problems they are trying to solve is nourished by a close relationship with local partners. Experience has taught the IRI that the strengthening of individuals and institutions in developing countries is one of the most important elements of their mission.

Famine Early Warning System Network. The United States supports the innovative application of science to alleviate risks related to existing climate variability or the potential for climate change through the Famine Early Warning System Network (FEWS NET). FEWS NET provides decisionmakers with the information to respond effectively to drought and food insecurity by analyzing remote-sensing data and ground-based meteorological, crop, and rangeland observations to identify early indications of potential famine. In addition to using data produced by host governments for its analyses, FEWS NET uses data from satellite imagery (NDVI and Meteosat Rainfall Estimation images) that it receives every 10 days throughout the year. FEWS NET operates in 20 countries in Africa, three countries in Central America, and in Haiti and Afghanistan.

RANET. Since the mid-1990s, the United States has provided support through NOAA and USAID's Office for Foreign Disaster Assistance (OFDA) to build the capacity of institutions and communities in Africa to generate, validate, and apply seasonal climate forecasts to plan for and respond to natural disasters such as droughts, tropical cyclones, and floods. The capacity building effort was achieved through an international framework called Climate Outlook Forums, which are the most trusted sources of seasonal forecast information and are the main conduits for generating and disseminating seasonal climate forecasts in Africa. Additionally, the United States, through NOAA's

long time partnership with the USAID-OFDA, supports the communication of seasonal climate information via radio and Internet technology called RANET. The RANET is a simple, cost-effective, and adaptable communication system that provides seasonal forecast information to remote areas in developing countries such as Africa.

International Climate Research Applications. Developing countries of Latin America and the Caribbean, Africa, Southeast Asia, and the South Pacific are vulnerable to climate variability and related environmental risks (e.g., droughts and floods) and may not be able to take advantage of opportunities such as advances in science and technology. As a result, these countries often bear a disproportionate share of the social and economic consequences of climate variability. Understanding the science of climate variability and using this insight to develop decision tools and methodologies is essential to enhancing informed planning and decisionmaking to reduce the impacts of climate variability and other environmental changes in these countries. An important CCSP goal is to support the development of scientific capabilities and the application of scientific tools in developing countries, and to promote the participation of developing country scientists and their institutions to fully participate in research, observation, and data management.

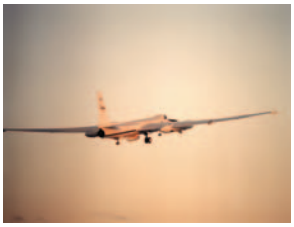
The Environment, Science, and Development (ESD) program of NOAA's Climate and Societal Interaction initiative contributes to the above CCSP goal. The ESD program facilitates the work of international scientific communities to conduct interdisciplinary, stakeholder-oriented, and on-site research designed to produce scientifically based tools and methods to underpin decisions to mitigate the impact of climate variability and change. Additionally, ESD's support will continue to contribute to building capabilities of scientists and institutions in Latin America, the Caribbean, Africa, Southeast Asia, and the South Pacific to effectively utilize climate information for managing climate risks such as droughts, floods, tropical cyclones, storm surges, etc. and for reducing the impact on economies and natural resources in developing countries.

ESD's support and collaboration with other partners such as USAID-OFDA have resulted in increased awareness of the value of climate information, and have better enabled decisionmakers in both the private and public sector who use climate information in decisionmaking and planning to mitigate hydrometeorological disasters and for natural resource management. In FY 2004, the ESD program supported a number of international climate research activities. These were designed to develop scientific capability in a number of developing countries in Latin America, the Caribbean, and Africa. Selected activities included:

- The "Regional capacity building for adapting to the impacts of climate variability and climate change in coastal zones of the Southern African Community (SADC) region" workshop contributes to NOAA's environmental literacy, outreach and education, and international collaboration in the African region. In addition, the

initiative represents an activity of the U.S./South Africa Climate Change bilateral initiative aimed at capacity building for users of climate change data.

- The "Seasonal Climate Prediction and Management of the Panama Canal: Estimating the Benefits of Using Climate Forecast Information" project contributes to NOAA's decision-support research portfolio and is aimed at assessing the value of climate information for the real-time management of the water resources of the Panama Canal watershed.
- In the Greater Horn of Africa, commonly referred to as Eastern Africa, a group of NOAA-supported scientists developed seasonal climate prediction tools through analysis of intra-seasonal behavior of rainfall in that region. From the results of the work, negative Southern Oscillation Indices (SOIs) indicate the emergence of El Niño and positive SOIs indicate the coming of La Niña.
- NOAA supported scientists in Uganda as they investigated and documented traditional rainfall indicators, which will contribute to increased understanding of traditional forecasting methods and their harmonization with scientific forecasts. Harmonization will both improve the resolution of scientific forecasts and facilitate the adoption of the forecast by decisionmakers, particularly at the grass-roots level.



In FY 2006, CCSP, through ESD, will sponsor a variety of efforts to apply climate research information, including the following:

- Generating, validating, and disseminating seasonal rainfall forecasts for international regions of Asia, Latin America and the Caribbean, Southeast Asia, the South Pacific, and Africa
- Collaborating with IRI, regional climate forecasting and application centers, and NOAA's regional principal investigators to demonstrate the value of climate information through demonstration projects, development of decision-support resources, and use of earlier exploratory pilot project outputs in operational mode for application in specific decision contexts
- Building capacity and training of users for more effective and efficient utilization of climate information in their various decision domains
- Partnering with relevant boundary institutions such as agricultural extension agencies, non-governmental organizations, and other local and place-based organizations for effective interpretation, communication, and dissemination of climate information
- Continuing to provide technical support for the U.S. Climate Change Bilateral initiative projects.

Cooperation in Support of International Research Programs

The International Geosphere-Biosphere Programme. The IGBP, because of its strong international research programs and coordination, has drawn the participation of many U.S. scientists. The United States supports individual science programs as well as secretariat operations and coordination activities. IGBP and the other international global change research programs add value to national and other international research through scientific integration; design and implementation of international research frameworks agreed by the scientific community; efficient strategies for international resource allocation; and international networking, standardization of methodologies, intercomparisons, and syntheses.

The IGBP focuses on an integrated biogeochemical approach to Earth system science. It is currently moving from its first phase of research activities into a second phase of integrative projects that have as their emphasis the interfaces between various components of the Earth system – for example, land-ocean, ocean-atmosphere, etc. The IGBP undertakes a wide variety of activities to bring the international scientific community together to promote understanding of the Earth system.

Priorities for calendar years 2004 and 2005 included launching the Integrated Land Ecosystem-Atmosphere Processes Study, the Global Land Project, and the Ocean Research in Earth System Science project; restructuring the task force on Earth System analysis; integration and modeling; enhancing links to the observation community (e.g., via the Integrated Global Observing Strategy); assimilating data into models; and contributing to and supporting ESSP.

DIVERSITAS. DIVERSITAS is the international global research program for the study of biodiversity science. The program is predicated on the understanding that it is essential to characterize and understand ecosystems in order to fully understand the sensitivity and adaptability of those ecosystems. Such understanding of ecosystem composition, function, vulnerability, and resilience is critical to determining the potential impacts of a variety of potential environmental perturbations, including climate change. This understanding is at the heart of U.S. support of the DIVERSITAS program and biodiversity science in general. The DIVERSITAS program is supported by U.S. scientists involved in its core projects and related activities, and by CCSP support for the secretariat's central coordination, outreach, and other roles.

DIVERSITAS is now focusing on the implementation of its 2002 Science Plan, which articulates the structure and scientific objectives of DIVERSITAS for the next decade. In 2004, DIVERSITAS published implementation plans for two of its three core projects and worked on establishing an International Project Office (IPO) for each of these projects. The bioDISCOVERY project, dedicated to "taxonomy, monitoring,

and drivers of biodiversity change," established an IPO in Caracas, Venezuela, which opened in September 2004. The ecoSERVICES project is dedicated to "biodiversity, ecosystem functioning, and services." The bioSUSTAINABILITY project, dedicated to the "science at the basis of conservation and sustainable development," has funded and established an IPO in the United Kingdom. The first DIVERSITAS Open Science Conference is scheduled to take place in Oaxaca, Mexico, in November 2005.

International Human Dimensions Programme. IHDP is the major international program that coordinates research related to human contributions and responses to global change. IHDP and other international programs provide international coordination of research on a variety of climate-relevant issues and provide important leadership in developing interdisciplinary research frameworks for other national and international programs. IHDP has garnered substantial scientific interest in research on the human dimensions of global change involving a number of U.S. scientists and agencies.

IHDP is implemented through its four established core research projects – Global Environmental Change and Human Security (GECHS), Institutional Dimensions of Global Environmental Change (IDGEC), Industrial Transformation (IT), and Land-Use Land-Cover Change (LUCC) – as well as a number of joint efforts with the other major international global change research programs. The LUCC project is engaged in synthesizing much of the research that has been undertaken, highlighting research products and activities, because it will be phased out at the end of 2005. GECHS, IDGEC, and IT are entering their second phase and priorities for the next 5 years for these projects are being discussed within IHDP.

IHDP initiated an internal mid-term review of its main contributions to key questions of global change research in 2003. The review includes a comprehensive synthesis of IHDP's contributions to cross-cutting questions on Vulnerability/Resilience/Adaptation and Thresholds/Transitions regarding climate change. In addition to IHDP's internal assessment, the program's sponsors (ICSU and the International Social Science Council) are undertaking an external assessment of IHDP to be finalized in late 2005. The Sixth Open Meeting of the Human Dimensions of Global Environmental Change Research Community took place in Bonn, Germany, from 9-13 October 2005.

World Climate Research Programme. With its focus on climate prediction and determining the extent to which human activity influences climate, the WCRP directly addresses CCSP goals in climate change research. As a result, the United States and U.S. scientists have long been supportive of the WCRP's extensive activities, including hosting the U.S. Climate Variability and Predictability (CLIVAR) project office, the International Global Energy and Water Cycle Experiment (GEWEX) Project Office, and the Stratospheric Processes and their Role in Climate (SPARC) data center.

The WCRP was established in 1980, under the joint sponsorship of the WMO and ICSU, and has also been sponsored by UNESCO's Intergovernmental Oceanographic Commission since 1993. The two major objectives of the WCRP are to determine the extent to which climate can be predicted and the extent of human influence on climate. To achieve these objectives, the WCRP promotes essential research into the basic behavior of the physical climate system, and its relation to the broader Earth system and the needs of society. Outlined below are examples of activities from the WCRP's CLIVAR Programme, GEWEX, and the SPARC project.

The First International CLIVAR Science Conference was held on 21-25 June 2004 in Baltimore, Maryland. More than 640 scientists from 56 different countries attended, making it the largest WCRP conference to date. It addressed a number of themes central to CCSP efforts including short-term climate prediction; monsoons; the challenge of decadal prediction; understanding long-term climate variations; the role of the oceans in climate; human influence on climate; and application of climate science.

GEWEX is an international program within the WCRP initiated to observe, understand, and model the hydrological cycle and energy fluxes in the atmosphere, at the land surface, and in the upper ocean. There is large overlap between GEWEX's foci and those of CCSP, including a component to extend research products and results to applications. GEWEX has panels concentrating on "Radiation," "Hydrometeorology," and "Modeling and Prediction." Each panel consists of researchers from the global community. As an example, the GEWEX Americas Prediction Program, supported by NOAA and NASA, is considered a component of the Hydrometeorology panel of GEWEX, which helps coordinate similar international projects (called Continental-Scale Experiments).

Major outputs of GEWEX include the International Satellite Cloud Climatology Project, the Global Precipitation Climatology Project, the Global Water Vapor Project, and the International Satellite Land-Surface Climatology Project I and II data sets. A critical current program of GEWEX is the Coordinated Enhanced Observing Period that collects *in situ*, satellite, and model data necessary for critical climate research objectives and monsoon system studies. In recognition of interest in GEWEX, the United States hosts the International GEWEX Project Office.

The WCRP established the SPARC project in 1992 to consolidate knowledge on the role that the stratosphere plays in Earth's climate system. The initial goal of SPARC was to stimulate research in areas connecting the stratosphere and climate, which had not been receiving sufficient attention during the earlier international research focus on stratospheric ozone.

SPARC has initiated the GCM-Reality Intercomparison Project, is compiling a stratospheric reference climatology against which model results can be compared using global satellite data, and is providing best estimates of the temporal variability of climate forcing due to changes in stratospheric ozone and aerosols. The United States

hosts the SPARC data center, whose objective is to facilitate data exchanges between participating scientists.

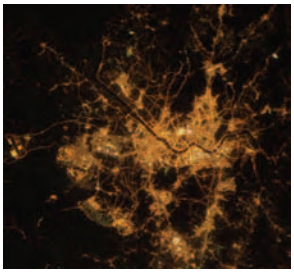
International Group of Funding Agencies for Global Change Research (IGFA). Through participation in IGFA, the United States is able to engage representatives from 20 national funding agencies with responsibility for funding global change research. Through annual plenary meetings, regular steering committee and staff group meetings, and other activities, member agencies are regularly informed about global change research programs, new initiatives, research infrastructure, and related issues. Topics of mutual interest are identified, and solutions determined and implemented through the relevant national processes, and, in some cases, through coordinated international effort. The United States, represented by Dr. Margaret Leinen, NSF, was elected Chair of the group for calendar years 2005 and 2006. During its chairmanship, the United States intends to maintain and improve communication internationally between agencies that fund global change research.

SysTem for Analysis Research and Training (START). START provides an international framework for outreach and capacity building by establishing and fostering regional networks of scientists and institutions in developing regions of the world. These networks conduct regional environmental change research, assess the vulnerabilities to and impacts of that change, and provide information to policymakers. In the course of their work, these networks enhance the scientific capacity of the regions in which they operate.

START has accomplished much during its relatively short existence. START has established five regional centers throughout Asia, Africa, and Oceania and has conducted over 70 regional meetings and training workshops. Sixty research collaborations are in process, many of them linked to U.S. institutions, such as IRI, the National Center for Atmospheric Research (NCAR), and various universities. Some 64 young scientist, 136 visiting scientist, and 24 doctoral fellowship awards have been made. Approximately 1,000 developing country scholars participate in START activities annually.

The quality of climate change science in the United States has benefited extraordinarily from these linkages with developing country scientists throughout the world, particularly in understanding potential impacts, coping and adaptation potentials, and strategies for building greater scientific and institutional capacities. The presence of young scientists from developing counties in many U.S. universities has also advanced American scientific and assessment capacities. The United States determined that START's capacity building and outreach efforts are sufficiently important to its interests that it hosts the international START secretariat in Washington, D.C.

Inter-American Institute for Global Change Research (IAI). The IAI is an intergovernmental treaty organization established in 1994 to promote collaborative research to understand and predict the integrated impact of present and future global change. The Institute allows the Western Hemisphere's scientists and their institutions to participate in collaborative research programs that they would not otherwise be able to afford, and allows regional observation coverage efforts that directly contribute to the goals of CCSP.



During FY 2005, the IAI carried out a merit-based peer review of proposals for a second round of Collaborative Research Networks (CRN). During FY 2006, this $10 million, 5-year program will begin funding approximately 10 networks involving over 50 scientists from 14 countries in projects ranging from the effects of climate change on emissions in mega-cities to ocean circulation changes in the South Atlantic. Each of these projects explicitly includes physical and social sciences in a closely integrated effort to provide information to decisionmakers, to train students as multidisciplinary Earth systems scientists, and to contribute to research efforts of the major global change research networks like the Earth Systems Science Partnership (DIVERSITAS, IGBP, IHDP, and WCRP). The IAI is a member of the international scientific planning committees of the 2005 open meetings of IHDP and DIVERSITAS.

At the Organization of American States Ministerial Summit in Lima, Peru, ministers of science and technology endorsed the IAI as a hemispheric initiative to be supported and strengthened. In addition to providing support for the CRN-2 program, the United States, through CCSP and NSF sponsorship of the IAI, will support a set of IAI scholarships for IAI-member state students in the Advanced Studies Programs at NCAR in FY 2006.

Under the leadership of the newly elected director, Dr. Holm Tiessen of the University of Göttingen, the IAI will continue its series of highly successful training institutes, now entering their sixth year. In FY 2005, two institutes were held. In October 2004, jointly with the IHDP, the IAI organized a Global Environmental Change Institute on Globalization and Food Systems in Costa Rica, and an Institute on Urbanization and Global Environmental Change in Latin America in Mexico City. In FY 2006, two additional institutes will be held: a Training Institute on Vulnerability Associated with Climate Variability and Climate Change in the Americas in Asunción, Paraguay, and jointly with the Pan-American Health Organization, a Training Institute on Climate and Health in the Americas in Kingston, Jamaica.

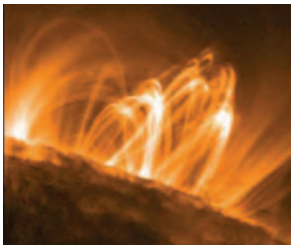
The Asia-Pacific Network for Global Change Research (APN). The APN's Scientific Programme Group and Intergovernmental Meeting (IGM) in April 2005 marked the end of APN's first decade of activity with a number of significant actions. These meetings reviewed and approved the Evaluation Report that had been prepared covering the APN's first decade and, building on this evaluation, the meetings

approved the APN's Second Strategic Plan covering the period 2005 to 2010. The IGM approved 24 projects for implementation in 2005-2006 under the APN regular program and an additional four projects for implementation under the APN program on Scientific Capacity Building and Enhancement for Sustainable Development in Developing Countries (CAPaBLE). One of the CAPaBLE projects, the Pacific Islands Institute on Climate and Extreme Events, has begun a series of in-country training programs in Samoa and Kiribati. The APN also recently launched its two calls for proposals for this year under its regular program and its CAPaBLE program.

The Northern Eurasia Earth Science Partnership Initiative (NEESPI). The NEESPI is a strategically evolving program of internationally supported Earth systems science research, which has as its foci issues in northern Eurasia that are relevant to regional and global scientific and decisionmaking communities. During 2004, the NEESPI developed a Science Plan (available at <neespi.gsfc.nasa.gov>. More and more partners in the United States, Europe, and Asia are getting involved in NEESPI activities. A U.S. Interagency Science Review meeting on NEESPI was held in December 2004. The goal was to brief representatives of U.S. and European agencies on the NEESPI Science Plan and attract more partners to NEESPI activities.

A boreal-zone data capacity workshop was held during 2004 and a non-boreal zone workshop is planned. The outcome of these workshops will be a comprehensive inventory of available space-borne and ground-based data sets for the region. This will facilitate preparation of a NEESPI Implementation Plan anticipated in the 2005-2006 time frame. The first NEESPI Science Session was held at the 2004 American Geophysical Union Fall meeting in San Francisco.

The NEESPI Science Team is being formed and the first projects for this team were selected in 2005 as a result of the Carbon Cycle Science NASA Research Announcement. More projects are likely to be selected in 2005 and 2006 from the proposals in response to the Water and Energy Cycle NASA Research Announcement, which included Terrestrial Hydrology and Land-Cover/Land-Use Change programs. The NEESPI leadership is working on formally including projects funded by other U.S. agencies and the European Commission under NEESPI auspices.



Bilateral Cooperation in Climate Change Science and Technology

In June 2001, President Bush committed the United States to developing with our international partners an effective and science-based response to the issue of climate change. Today the United States remains committed to working with others, including both developed and developing country partners, to promote cooperative and

collaborative approaches to address the global challenge of climate change. To that end, the U.S. Department of State is leading a major interagency effort to advance international cooperation in climate change science and technology.

Since June 2001, the United States has launched bilateral climate partnerships with 15 countries and regional organizations that, combined with the United States, account for almost 80% of global greenhouse gas emissions. Partnerships have been established with Australia, Brazil, Canada, China, Central America (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), the European Union, Germany, India, Italy, Japan, Mexico, New Zealand, Republic of Korea, Russian Federation, and South Africa. These bilateral initiatives seek to build on key elements of CCSP and CCTP, including research, observations, data management and distribution, and capacity building.

Substantive project-level work plans are now in place with each of these countries. Successful joint projects have been initiated in areas such as climate change science; clean and advanced energy technologies; carbon capture, storage, and sequestration; and policy approaches to reducing greenhouse gas emissions. The United States is also assisting key developing countries in efforts to build the scientific and technological capacity needed to address climate change.

Highlights from 2004 include a number of highly successful workshops convened under the auspices of the U.S. bilateral climate partnerships. Of particular note were the workshops held in cooperation with Japan, India, and Italy. Through the U.S.-Japan High Level Consultations on Climate Change, the United States and Japan hosted a workshop on the nexus of energy and climate issues, which took place in March 2004 in Kuala Lumpur, also in cooperation with the Government of Malaysia. In July 2004, the United States and India convened a workshop on climate change science in Manesar, India. Topics discussed at the workshop included seasonal forecasting, radiative effects of atmospheric aerosols, measurement and monitoring infrastructure enhancement, and ocean observations. In October 2004, the United States and Italy held a workshop on climate science and clean energy technologies in Venice, Italy.

Over the coming year, two key objectives for the bilateral activities will be the continued advancement of results-oriented programs and the fostering of substantive policy dialogs within all 15 of the bilateral climate change partnerships. In order to broaden U.S. cooperative efforts to advance a practical and effective global response to climate change, the United States will expand outreach and support to the developing country community, utilizing a regional approach where feasible.

Additional Climate-Related International Activities

11th U.S.-Japan Workshop on Global Climate Change. The United States and Japan, through the U.S.-Japan Agreement on Cooperation in Research and Development in Science and Technology, have conducted a series of climate-related workshops since 1990. These workshops are planned and managed by the CCSP Interagency Working Group on International Research and Cooperation and on the Japanese side by the Ministry of Education, Culture, Sports, Science, and Technology. The series has covered a wide variety of mutually agreed topics including Land-Use/Land-Cover Change (Fourth Workshop, held in 1996), Health and the Environment (Eighth Workshop, held in 2000), Climate and Water (Tenth Workshop, held in 2003), and many others. There have been many follow-up activities and publications as a result of this highly successful workshop series.

Planning is currently underway for the 11th Workshop, "Biodiversity, Ecosystem Function, and Dynamic Human-Nature Interactions," which will focus on the interactions among biodiversity, ecosystem function, and global change; summarize the recent achievements by ecological studies in the United States and Japan; and discuss how to advance U.S.-Japan collaborations in the future. This workshop will result in recommendations to improve long-term ecosystem monitoring, intercomparison of ecological models, establishment of a biodiversity database, satellite monitoring, and other topics. Future joint cooperative projects in this field between the United States and Japan will also be discussed.

Asia-Pacific Partnership on Clean Development and Climate. On July 27, 2005, the United States joined with Australia, China, India, Japan, and South Korea to create a new Asia-Pacific partnership on clean development, energy security, and climate change. This new results-oriented partnership will allow our nations to develop and accelerate deployment of cleaner, more efficient energy technologies to meet national pollution reduction, energy security, and climate change concerns in ways that reduce poverty and promote economic development. The six Asia-Pacific partners will build on our countries' strong history of common approaches and demonstrated cooperation on clean energy technologies.

Regional Cooperation on Global Change Research in Africa. A workshop on Regional Cooperation on Global Change Research in Africa was held on 22-24 September 2005 in Nairobi, Kenya, under the aegis of the ESSP. Over 50 scientists from 23 countries across Africa met with scientists from other countries to consider needs and opportunities for such regional cooperation. Participants supported developing an African network for global change research to focus on the following suggested key scientific themes: water and climate modeling; desertification; land degradation, biodiversity, and food security; health and pollution; and marine ecosystems.

APPENDIX
The Climate Change Science Program Participating Agencies

APPENDIX

THE CLIMATE CHANGE SCIENCE PROGRAM PARTICIPATING AGENCIES

The following pages present information about the contributions to the CCSP of each of the program's participating agencies:

- Department of Agriculture (USDA)
- Department of Commerce / National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Health and Human Services (HHS)
- Department of the Interior / U.S. Geological Survey (DOI/USGS)
- Department of State (DOS)
- Department of Transportation (DOT)
- Agency for International Development (USAID)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Smithsonian Institution (SI).

Principal Areas of Focus, Program Highlights for FY 2006, and Related Research are summarized for each agency.

U.S. DEPARTMENT OF AGRICULTURE

Agricultural Research Service (ARS)
Cooperative State Research, Education, and Extension Service (CSREES)
Economic Research Service (ERS)
Forest Service (FS)
Natural Resources Conservation Service (NRCS)

Principal Areas of Focus

USDA conducts and sponsors a broad range of research that supports improved understanding of the roles that terrestrial systems play in influencing climate change and the potential effects of global change on agricultural, forest, and range systems, and on developing management systems to maintain and enhance food, fiber, and forestry production under changing conditions. Specific components of USDA's research program seek to determine the significance of terrestrial systems in the global carbon cycle, to promote the capture and use of methane emitted from livestock waste facilities for on-farm power generation, to assess the potential of bioenergy as a substitute for fossil fuels, to identify agricultural and forestry activities that can help reduce greenhouse gas concentrations and increase carbon sequestrations, to quantify the risks and benefits arising from environmental changes to agricultural lands and forests, and to develop management practices that can adapt to the effects of global change, including potential beneficial and adverse effects. USDA's research agencies also support the Department in responding to the President's directive to develop and implement accounting rules and guidelines for carbon sequestration projects, and in contributing to the synthesis and assessment reports identified in the *CCSP Strategic Plan*.

Program Highlights for FY 2006

ARS's national program on global change research addresses carbon cycle and carbon storage, trace gas emissions and sinks, impacts of environmental changes on agricultural systems, and feedbacks among agricultural systems, weather systems, and the water cycle. Ongoing research focuses on analyzing risks and benefits associated with global change and developing management strategies to sustain agricultural production and reduce agricultural greenhouse gas intensity (i.e., net greenhouse gas emissions per unit of commodity produced). New research being proposed will enhance ARS's program by placing additional emphasis on quantifying agricultural contributions to greenhouse gas emissions and soil carbon sequestration and developing practices to mitigate these greenhouse gas emissions and increase soil carbon sequestration while maintaining land in productive agricultural uses. Environmentally friendly and economically feasible alternatives to the use of stratospheric ozone-depleting methyl bromide will be developed as a treatment to control pests.

CSREES will continue to support the USDA UV-B Monitoring and Research Network Program (UVMRP). Information from this research network is combined with satellite-based measurements to provide an accurate climatological UV-B irradiance database to document long-term trends and to

support research and assessment of the potential for damage to ecosystems. The program has been providing ground-based support to NASA's Total Ozone Monitoring Spectrometer (TOMS) instruments, by providing radiometer data that have been used to assess UV-B geographic distribution, trends, and year-to-year variability in the United States. Since 2002, the NASA TOMS and AERONET (**AE**rosol **RO**botic **NET**work) programs and USDA UVMRP have shared equipment, personnel, and analysis tools to quantify aerosol absorption using ground-based radiation measurements. CSREES will continue to support global change research through the National Research Initiative (NRI) Competitive Grants Program and formula-funded programs. NRI includes programs for carbon and water cycles, land-use and -cover change, ecosystem, and human dynamics research. CSREES is using the *CCSP Strategic Plan* in formulating priorities under the NRI program and in shaping specific grant announcements.

The Forest Service has identified the following key issues for future program emphasis: (1) Improve observations of forest carbon stocks and flows based on development and deployment of improved field measurement techniques and measurements integration, and initiate a forest carbon-monitoring program component of the interagency North American Carbon Program (NACP); (2) integrate observations with process-level studies to better understand, forecast, and manage the relationships between forest and rangeland systems and climate; (3) develop and help deploy forest management systems and technologies that increase carbon sequestration, provide fossil-fuel offsets, enhance productivity, and maintain environmental quality; (4) provide integrated prediction models of forest carbon dynamics; and (5) improve technical information for forest greenhouse gas accounting rules and guidelines.

Related Research

In addition to research under the Climate Change Science Program, USDA maintains an active program to improve measurement and accounting of greenhouse gases from agriculture and forestry systems. USDA is developing technologies and practices to improve the utilization of biomass energy and bio-based products. The Forest Service, NRCS, ARS, CSREES, and the Rural Development mission area support biofuels and biomass-related research and development. NRCS and the Forest Service are developing new measurement technologies, analytic techniques, and information management systems to measure the benefits of conservation practices on carbon fluxes and greenhouse gas emissions. These research and development activities are reported under the Climate Change Technology Program. USDA also collects data on land use, resource conditions, and climate through the National Resources Inventory, the Forest Inventory and Analysis Program, the Soil Climate Analysis Network (SCAN), and the Snowpack Telemetry (SNOTEL) system. These networks provide critical data and information on the status of land uses in the United States in support of CCSP research.

DEPARTMENT OF COMMERCE / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Principal Areas of Focus

NOAA's climate mission is: "To understand and describe climate variability and change to enhance society's ability to plan and respond." The long-term climate efforts of NOAA are designed to develop a predictive understanding of variability and change in the global climate system, and to advance the application of this information in climate-sensitive sectors through a suite of process research, observations and modeling, and application and assessment activities.

Climate activities in NOAA range significantly in terms of time and space scales for both research and services. Products are developed to support a range of international, national, regional, and local users. Specifically, NOAA's research program includes ongoing efforts in observations, with an emphasis on oceanic and atmospheric dynamics, circulation, and chemistry; understanding and predicting ocean-land-atmosphere interactions, the global water cycle, and the role of global transfers of carbon dioxide among the atmosphere, ocean, and terrestrial biosphere in climate change; improvements in climate modeling, prediction, and information management capabilities; the projection and assessment of variability across multiple time scales; the study of the relationship between the natural climate system and society, and the development of methodologies for applying climate information to problems of social and economic consequences; the relationship of climate to coastal and marine ecosystems; and archiving, managing, and disseminating data and information useful for global change research.

Program Highlights for FY 2006

Observations and Analysis

The goal of NOAA's Climate Observations and Analysis effort is an integrated ocean and atmosphere observing system in support of a predictive understanding of the global climate system. The NOAA observing system will be fully integrated into the U.S. Integrated Earth Observing System (IEOS). This will be implemented through a tiered and integrated observational network that provides sustained global and U.S. monitoring of key climate-related parameters; an end-to-end data management system to provide climate-quality information and respond to the projected data growth rates; and sophisticated analyses to differentiate climate variability and change as a result of natural processes and human activities.

Activities in FY 2006 will:

- Expand deployment of the U.S. component of the global Atmospheric and Ocean Observing System, with emphasis on reduced uncertainty in sea level, sea-surface temperature, and ocean carbon.
- Achieve global coverage with the 3,000-float Argo array.
- Achieve a modest increase in the number of Global Upper Air Network (GUAN) and Global Surface Network (GSN) stations.
- Increase the pilot Indian Ocean array with two additional moorings, for a total of five moorings in FY 2006.

- Collect upper ocean temperature data by maintaining expendable bathythermograph probes globally along repeated ship track lines.
- Report on progress in developing a new atmospheric reanalysis data set to more fully document weather and climate variability over the entire 20th century.
- Report on temperature trends in the lower atmosphere, and progress toward understanding and reconciling differences in various estimates.

Climate Forcing

The goal of NOAA's Climate Forcing activities is to provide the understanding needed to link emissions to the radiative forcing of climate change. The specific aim is to attain a timely understanding of atmospheric carbon dioxide trends—both natural and human-produced—and to provide timely information on the climate roles of the radiatively important trace atmospheric species (e.g., fine particle aerosols and ozone) needed to broaden the suite of non-carbon options available for climate change policy support. A quantitative characterization of climate change forcing from greenhouse gas species is needed for input to global climate models to optimize predictions of what climate changes could result from policy decisions.

Activities in FY 2006 will:

- Continue implementation of the carbon cycle observing system.
- Estimate North American carbon dioxide uptake through new data and models.
- Expand the carbon cycle global network into under-sampled regions (e.g., Africa and South America).
- Conduct retrospective model simulations of the climate impacts due to 1980–2000 radiative forcing.
- Develop an instrument package for an airborne aerosol observatory.
- Conduct field and laboratory studies of factors that influence the radiative effect of aerosols.
- Continue the global ocean carbon inventory along cross-sections in the North Pacific.
- Expand the coastal carbon dioxide measurement network, which will provide information on atmosphere-ocean carbon dioxide exchange and atmospheric carbon dioxide at the continental boundary.
- Quantify the seasonal and interannual variations of air-sea carbon dioxide fluxes in the North Atlantic and North Pacific via measurements of surface-ocean pCO_2, conducted by research and volunteer observing ships as they are underway.

Predictions and Projections

The goal of NOAA's Climate Predictions and Projections component is to provide a seamless suite of climate outlooks and projections on intraseasonal, seasonal, interannual, and multi-decadal time scales to facilitate management of risks and opportunities related to climate variability and change.

Activities in FY 2006 will:

- Run climate projections for research and assessment based on emission scenarios developed through the Climate Change Technology Program. Likely case studies will include exploring the range of plausible future environmental consequences of different emission rates resulting from combinations of different technologies.
- Report on results of field experiments of processes influencing warm-season precipitation over the southwestern United States, and prospects and needs for improving summertime rainfall forecasts in this region.

- Develop prototype methods for applying climate information to address practical challenges associated with natural resource management and hazard mitigation.
- Support diagnostic studies that contribute to the planned Tropical Atlantic Climate Experiment (TACE) and Atlantic Marine ITCZ (AMI) process study of U.S. CLIVAR in the tropical Atlantic—U.S. components of the international African Monsoon Multidisciplinary Analyses (AMMA) project—to improve coupled models used for climate predictions.
- Support observing system simulation experiments for the planned Pacific Upwelling and Mixing Physics process study, a contribution to U.S. CLIVAR.

Regional Decision Support

NOAA's Regional Decision Support effort aims to help society mitigate climate-related risks by translating the results of climate research into usable products for policymakers and decisionmakers, and by delivering that climate information operationally. The activities address an increase in the demand for traditional services (like routine seasonal forecasts and data products), accompanied by new requirements for expanded drought information and an increased emphasis on forecasts of risks of high-impact weather events associated with El Niño and La Niña, as well as sea-level inundation.

Activities in FY 2006 will:

- Initiate activities for mitigating the effects of drought through the National Integrated Drought Information System (NIDIS).
- Conduct exploratory workshops for research and evaluation to develop sector research (e.g., coastal, sea-level rise, drought, agriculture).
- Develop curriculum and communication tools for teachers and decisionmakers.
- Support transition of research products to applications through the NOAA Climate Transition Program.

Related Research

In addition to focused CCSP efforts, related activities include developing forecasts of changes in fishery, coastal, and coral-reef resources in response to climatic changes in oceanic water mass distributions, sea-surface temperature, sea-level rise, and coastal runoff; developing a prototype Arctic observing system for monitoring sea ice, heat content, freshwater, and ecosystem indicators; enhancing prediction and observation systems in support of weather and seasonal to interannual climate forecasts; determining actual long-term changes in temperature and precipitation over the United States through long-term (50+ years) operation of the U. S. Climate Reference Network; continuing to build out the Comprehensive Large-Array Storage System (CLASS) to meet the growth in observational data from satellite and radar systems; and facilitating the dissemination of global change information.

DOC's National Institute of Standards and Technology (NIST) provides measurements and standards that support accurate and reliable climate observations. NIST also performs calibrations and special tests of a wide range of instruments and techniques for accurate measurements. NIST provides a wide array of data and modeling tools that provide key support to developers and users of complex prediction models.

DEPARTMENT OF DEFENSE

Principal Areas of Focus

The Department of Defense—while not supporting dedicated global change research—continues a history of participation in the Climate Change Science Program through sponsored research that concurrently satisfies national security requirements and stated goals of the CCSP. All data and research results are routinely made available to the civil science community. DOD science and technology investments are coordinated and reviewed through the Defense Reliance process and published annually in the *Defense Science and Technology Strategy*, the *Basic Research Plan*, the *Defense Technology Area Research Plan*, and the *Joint Warfighting Science and Technology Plan*.

Program Highlights for FY 2006

Satellite Sensors and Observations

As part of National Polar-orbiting Operational Environmental Satellite System (NPOESS) operations, DOD will fund 50% of the satellite and environmental sensor suites as a result of the convergence of national remote-sensing programs. NPOESS will monitor global environmental conditions, and collect and disseminate data related to weather, atmosphere, oceans, land, and near-space environment. The NPOESS program is managed by the tri-agency Integrated Program Office run by DOC, DOD, and NASA.

Global Observations and Models

The Navy is a principal member of the National Oceanographic Partnership Program (NOPP). Key elements within NOPP are the Integrated Ocean Observing System Data Management and Communications (DMAC) program, the Global Ocean Observation System (GOOS), the Global Ocean Data Assimilation Experiment (GODAE), and the National Federation of Regional Associations (NFRA). Within NOPP, a broad partnership of institutions is collaborating on developing and demonstrating integrated ocean observations systems, data management systems, and eddy-resolving real-time global- and basin-scale ocean prediction systems. The HYbrid Coordinate Ocean Model (HYCOM) is part of the GODAE program. The systems will run efficiently on a variety of massively parallel computers, and will include sophisticated techniques for assimilation of satellite altimeter sea-surface height and sea-surface temperature data, as well as *in situ* temperature, salinity, and float displacement. The goal of this project is to develop and implement a comprehensive data management and distribution strategy that allows easy and efficient access to HYCOM-based ocean prediction system outputs to coastal and regional modeling sites; to the wider oceanographic and scientific community, including climate and ecosystem researchers; and to the general public, especially students in intermediate and high schools. This is to be accomplished through a data-sharing system using existing open source software packages to distribute data via the internet. The HYCOM Data Sharing System is built upon two existing software components: the Open Project for a Network Data Access Protocol (OPeNDAP) and the Live Access Server (LAS). OPeNDAP is the middleware that provides uniform binary-level access to scientific data on the internet.

Polar Regions Research

The *CCSP Strategic Plan* places priority on the polar and subpolar regions, which have exhibited more rapid changes than the lower latitudes. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) responds to the needs of the military, but much of the research also benefits the civilian sector and is funded by non-military customers such as NSF, NOAA, NASA, DOE, and State governments. DOD research has examined impacts of climate change on retreating Arctic sea ice to help define requirements for U.S. Coast Guard ice-breaking ships over the next 30 years. Satellite data show that the extent of Arctic sea ice has decreased by about 10%, and the sonar data collected by U.S. Navy submarines in the Arctic between 1957 and 2000 show the average ice thickness has decreased between 33 and 42%.

CRREL and the University of Alaska are developing an internet-accessible Alaska Engineering Design Information System (AEDIS)—an analytic toolkit for engineers that presents a broad array of geospatial terrestrial, oceanic, and atmospheric environmental data in a Geographic Information System (GIS). CRREL, in partnership with NSF and DOT has established a National Geotechnical Experimentation Site (NGES) as a long-term study area for research on permafrost properties and its responses to human and natural disturbances.

In response to the observations of the rapid pace of environmental change in the Arctic, DOD scientists participate in the interagency Study of Arctic Environmental Change (SEARCH). CRREL scientists have instrumented ice-observing buoys in the Arctic ice pack to monitor changes in ice thickness and snow cover throughout the year. These buoys have also been incorporated into the NSF-sponsored North Pole Environmental Observatory in the central Arctic, and are an integral part of the International Arctic Buoy Program (IABP), which has provided fundamental knowledge of the variations in Arctic climate and circulation patterns over the last 25 years.

DOD scientists participated in the *Arctic Climate Impact Assessment* (ACIA) to assess the ongoing and future changes in Arctic climate and its impacts on people, ecosystems, and infrastructure. Monitoring changes in the state of the ground continues to be of collective interest to DOD, NOAA, and USGS. The Cold Land Processes Experiment (CLPX) uses airborne instruments to retrieve snow pack, frozen ground and water, and vegetation properties for monitoring water resources and hazards. NASA, DOD, and NOAA are developing the 2010 HYDROS satellite mission to measure global soil moisture and freeze-thaw cycles. Improved satellite remote-sensing techniques to monitor changes in the Arctic ice pack are being developed by collaborative teams of agency researchers.

Scientists from CRREL and other institutions examined the seasonal evolution of albedo and the snow and ice mass balance north of Barrow, Alaska, and determined that the observed rates of sea-ice surface melting are typically at least twice as high as rates observed in the pack ice during the Surface Heat Budget of the Arctic (SHEBA) project referenced in the FY 2004-2005 edition of *Our Changing Planet*.

Techniques for high-resolution sea-ice model simulations have also been developed to understand the formation of leads and ridges in Arctic ice cover and its relationship to atmosphere and ocean circulation.

Related Research

Other DOD-sponsored research and supporting infrastructure, not described above, also contribute to observing, understanding, and predicting environmental processes related to global change. Associated research programs include theoretical studies and observations of solar phenomena, monitoring and modeling of unique features in the middle and upper atmosphere, terrestrial and marine environmental quality research, and energy conservation measures. DOD's continued investment in environmental infrastructure—such as the Oceanographic Research Vessel Fleet, CRREL, and the various services' operational oceanographic and meteorological computational centers—will continue to provide data and services useful to the CCSP.

DEPARTMENT OF ENERGY

Principal Areas of Focus

Research supported by DOE's Office of Science is focused on the effects of energy production and use on the global climate system, primarily through studies of climate response. Research includes climate modeling, atmospheric properties and processes affecting Earth's radiation balance (including clouds and aerosols), and sources and sinks of energy-related greenhouse gases (primarily CO_2). It also includes research on consequences of climatic and atmospheric changes on ecological systems and resources, development of improved methods and models for conducting integrated economic and environmental assessments of climate change and of options for mitigating climate change, and education and training of scientists for climate change research.

Program Highlights for FY 2006

DOE will continue the support of climate change research at its National Laboratories and other public and private research institutions, including universities. In support of CCSP, the Office of Science research program includes activities in four areas to provide the data and predictive understanding that will enable objective, scientifically rigorous assessments of the potential for, and consequences of, human-induced climate change: climate and hydrology, atmospheric chemistry and carbon cycle, ecological processes, and human dimensions.

Climate and Hydrology

DOE will continue to develop, improve, evaluate, and apply fully coupled atmosphere-ocean-sea ice-land surface general circulation models (GCMs) that simulate climatic variability and change over decadal to centennial time scales. Climate modeling activities planned for FY 2006 will place particular emphasis on analyzing climate feedbacks and sensitivity to natural and human-induced forcing, as well as on enhancing climate modeling systems. DOE will lead the effort on the CCSP Synthesis and Assessment Product 3.1, *Climate Models: Model Sensitivities, Feedbacks, and Uncertainties*.

In FY 2006, DOE will complete the suite of Community Climate System Model (CCSM) and Parallel Climate Model (PCM) ensemble simulations of climate change projections under various forcing scenarios as part of the U.S. contribution to the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report*. IPCC model simulations from major national and international high-end modeling centers will be archived at Lawrence Livermore National Laboratory (LLNL)/Program for Climate Model Diagnosis and Intercomparison (PCMDI), and made accessible to the climate research community. DOE will continue to support model development of the CCSM to incorporate atmospheric chemistry and coupled biogeochemistry, in addition to improved physics and dynamics. DOE will also continue ongoing development of high-resolution comprehensive coupled GCMs that incorporate more accurate and verified representations of clouds and other important climatic processes. Finally, DOE will continue support of innovative approaches to climate model development—for example, the geodesic grid model intended to lead to a prototype climate model that could potentially overcome some of the problems and limitations of current generation climate models.

Collection and analysis of data from DOE's Atmospheric Radiation Measurement (ARM) Cloud and Radiation Test Bed (CART) sites will continue in FY 2006 to improve understanding of the radiative transfer processes in the atmosphere and to formulate better parameterizations of these processes, especially cloud and aerosol effects for use in climate models. DOE will also report on results of the Mixed Phase Arctic Cloud Experiment (M-PACE), a major field experiment to improve scientific understanding of the dynamic processes in Arctic mixed-phase clouds, including cloud microphysical processes and radiative transfer through Arctic clouds. The ARM Mobile Facility (AMF) will be deployed in Niger, Africa, in FY 2006 as part of the field phase of the African Monsoon Multidisciplinary Analysis (AMMA) to obtain atmospheric and radiation data on meteorological conditions ranging from deep, tropical convective clouds in the humid tropical air masses prevalent in the wet season to the aerosol-laden dry air masses found during the dry season. AMMA field data will provide unique opportunities to evaluate and improve the parameterization schemes used in climate models across a wide range of meteorological conditions. A measurement campaign around the ARM site in Darwin, Australia, is in planning for FY 2006 that will focus on the effects of cirrus clouds on the transfer of radiation in the atmosphere. This so-called Tropical Warm Pool International Cloud Experiment (TWP-ICE) will employ multiple research aircraft and balloon-borne meteorological sensors from an array of sites to measure cloud properties and their impacts on the transfer of radiation in the atmosphere throughout the storm life cycle as well as the atmospheric state. Data from this experiment will be used to both evaluate and test how well existing models simulate cloud properties and to improve the modeling of cloud properties and their effects on the transfer of radiation in the atmosphere.

Atmospheric Chemistry and Carbon Cycle

In FY 2006, DOE's Atmospheric Science Program will continue research begun in FY 2005 to reduce uncertainties in aerosol radiative forcing of climate. Research will include modeling, instrument development, laboratory measurements, and field measurements. The scope of research will include sources of particles and gaseous precursors; transport of particles and gaseous precursors on local to regional and greater spatial scales; concentrations of gas-phase aerosol precursors; aerosol characterization, including optical properties, size distribution, number concentrations, humidity effects, cloud condensation nuclei properties, single particle composition, and physical and chemical characterization of carbonaceous particles; transformations, including gas-phase transformations, condensed-phase and surface transformations, gas-to-particle conversion, new particle formation, evolution of aerosol size and composition, aerosol dynamics, aerosol activation, size distribution, precipitation development, and in-cloud and below-cloud scavenging; and atmospheric radiation.

In FY 2006, DOE's Atmospheric Science Program will analyze data from its FY 2005 marine stratus field campaign in collaboration with ARM, and will conduct a major campaign in collaboration with other CCSP agencies to examine and characterize changes in aerosol composition, size distribution, light scattering coefficient, absorption coefficient, optical depth, soot-specific absorption, and radiative fluxes at the surface in a large megacity plume. Results from these campaigns will be utilized to develop or improve detailed models of aerosol processes required by the climate modeling community. These activities support *CCSP Strategic Plan* Goals 2 and 3, and address Questions 3.1 and 3.2.

DOE's carbon cycle research will continue to improve understanding of the role and importance of terrestrial and marine ecosystems in the global carbon cycle. The research in FY 2006 will address the research questions and elements described in Chapter 7 of the *CCSP Strategic Plan*. DOE will continue its contributions to the North American Carbon Program (NACP) through the support of

experimental field studies, observations, and modeling of the terrestrial carbon cycle. Major commitments in FY 2006 include continued support for a variety of experimental studies, syntheses of some of the carbon cycle research results, and support of new studies to better understand the carbon impacts of climate-related effects on ecosystems. These efforts will include the development of an integrated framework for using AmeriFlux measurements and ecosystem models to understand terrestrial carbon cycling processes. It will yield information on ecosystem states and carbon sinks in real-time, and will be an effective tool for investigating fundamental ecological processes that are difficult to observe directly. DOE will also support a model-based comparison of "bottom up" (distributed ecosystem models driven by land surface and meteorological information) and "top down" (inferring spatially distributed surface fluxes from atmospheric measurements) approaches to estimating ecosystem carbon dioxide fluxes at the regional scale, focusing on the Southern Great Plains of the United States. Predicted temporally and spatially resolved gross and net carbon dioxide fluxes will be made available to researchers to help evaluate NACP-related results for regional carbon dioxide exchange, climate, and land use. DOE will also support research to incorporate biogeochemical and physiological responses and feedbacks associated with climate change in terrestrial ecosystem models and to link the ecosystem models with climate simulation models.

In ocean carbon cycle research, DOE will continue to enhance the understanding, in mechanistic terms, of the biological controls on net carbon dioxide uptake by the ocean (from the atmosphere). In FY 2006, the ocean science program will place an emphasis on understanding what the ecological and biogeochemical effects have been of the net uptake of carbon dioxide by the ocean (and related chemical changes in seawater) during the past 2 centuries, and what ecological and biogeochemical effects may result from further net carbon dioxide uptake during the coming decades. The program will continue to take advantage of the availability of data on newly sequenced diatom and marine bacterial genomes and will incorporate findings on microbially mediated transformations of carbon and nitrogen into models of the ocean carbon cycle.

Ecological Processes

DOE will continue to design, implement, and maintain large-scale and long-term experimental field manipulations of environmental factors affected by energy production in important North American ecosystems. This includes support of the Free-Air CO_2 Enrichment (FACE) experimental facilities for study of the response of terrestrial ecosystems to elevated atmospheric concentrations of carbon dioxide and/or other trace gases such as ozone. The goal is to understand, and be able to predict, effects of environmental change and variability on the structure and functioning of terrestrial ecosystems. The research focuses on the physiology, growth, and reproduction of plants and microbes; nutrient and water cycling in ecosystems; plant community dynamics; plant-microbe interactions; and acclimation and adaptation of plants, microbes, and whole ecosystems to environmental change and variability.

Final data collection will occur in FY 2006 from the large-scale Throughfall Displacement Experiment (TDE) located in a deciduous hardwood forest in eastern Tennessee. TDE—a continuous study begun in 1993 of whole-forest responses to altered precipitation—has served as an important source of data for the development and testing of a wide range of ecosystem models. In FY 2006, the precipitation manipulations will be ended and extensive characterization of the effects of 13 years of chronic changes in the precipitation inputs to the forest ecosystem will be completed. An ongoing synthesis of existing data, model projections, and conceptual hypotheses of the interactions and feedbacks between terrestrial ecosystems and the climate system is expected to be completed in FY 2006. The synthesis will draw on

output from workshops, reviews of existing scientific literature, and new model calculations to provide an initial definition of the requirements for ecosystem observations needed to quantify ecological feedbacks to climate and atmospheric composition. The definitions will be directed in part at enhancing the use of existing observing systems, but will also consider needs for the development of new observing capabilities. The activities to be completed in FY 2006 will focus on the western United States, but are expected to provide a solid scientific base for similar activities directed at other regions.

Experimental research will also be continued in FY 2006, including field manipulations of temperature, precipitation, carbon dioxide concentration, and/or enhanced atmospheric nitrogen deposition in a boreal forest, arid shrubland, temperate old field grassland undergoing succession, and a temperate deciduous forest. Such experiments will provide the data and information needed to evaluate (test) the ability of ecological models to realistically predict effects of environmental change and variability on terrestrial ecosystems; such models form the basis of most assessments of potential effects of environmental change on ecosystems. The research initiative implemented in FY 2004 dealing with "scaling" in ecological systems will also be continued in FY 2006. This initiative will continue to examine how quantitative information obtained at the level of macromolecules (e.g., genes and enzymes) can be used to understand and predict how processes and states of whole terrestrial ecosystems would be affected both directly and indirectly by natural and human-induced environmental changes, such as climatic changes caused by energy production.

Human Dimensions

The DOE human dimensions program will continue its support of fundamental research to develop and improve data, models, and methods for use by others to analyze and assess the economic, social, and environmental implications of climate change and of various potential policy options for mitigating or adapting to climate change. In FY 2006, research will continue on climate change technology innovation and diffusion, with particular emphasis on understanding forces that will assist the prediction of the penetration of new technologies to non-Organisation for Economic Cooperation and Development (OECD) countries such as China. Projections of energy demand and associated greenhouse gas emissions will be improved by analyzing demographic variables. The research is using three case studies: the United States, China, and Indonesia. The emphasis will continue to be on household composition, using survey data to estimate relationships with energy use. The objective is to improve projections of energy demand in integrated assessment models by taking into account variations in energy use across household types. Ongoing investigations of factors that have affected the adoption in the past of technologies for controlling nitrous oxide and sulfur emissions from power plants in the United States will provide new information to help infer future adoption of new carbon emission technologies. DOE's human dimensions research in FY 2006 will also include analysis and application of explicit models of methane and other non-CO_2 greenhouse gas emissions. This will result in revised supply curves and improved estimates of costs associated with emission reductions in one or more of the integrated assessment models used to assess the economic costs and benefits of alternative climate change technology options for reducing greenhouse gas emissions.

DOE will also continue support of its Global Change Education program in FY 2006, including support of undergraduate and graduate students through the DOE Summer Undergraduate Research Experience (SURE) and the DOE Graduate Research Environmental Fellowships (GREFs). Support will also be continued for the Carbon Dioxide Information and Analysis Center (CDIAC) to enable it to

respond to data and information requests from users all over the world who have a need for data on, for example, greenhouse gas emissions and concentrations.

Related Research

DOE plays a major role in carbon sequestration research to reduce atmospheric concentrations of energy-related greenhouse gases, especially carbon dioxide, and their net emissions to the atmosphere. The research builds on, but is not part of, the CCSP. It focuses on both developing the scientific information needed to enhance the natural sequestration of excess atmospheric carbon dioxide in terrestrial and ocean systems, and assessing the potential environmental consequences and ancillary benefits of that enhanced sequestration. It also includes research to develop biotechnological approaches for sequestering carbon either before or after it is emitted to the atmosphere. Funding for DOE's carbon sequestration research is part of the Climate Change Technology Program (CCTP). CCTP also provides related research funding to support a balanced and diversified portfolio of advanced technology research and development, focusing on energy-efficiency enhancements; low-GHG-emission energy supply technologies; carbon capture, storage, and sequestration; and technologies to reduce emissions of non-CO_2 gases. Together, CCSP and CCTP will help lay the foundation for future progress. Advances in the climate change sciences under CCSP can be expected to improve understanding about climate change and its impacts. Similarly, advances in climate change technology mitigation under CCTP can be expected to bring forth an expanded array of advanced technology options at a lower cost that will reduce greenhouse gas emissions.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

National Cancer Institute (NCI)
National Eye Institute (NEI)
National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS)
National Institute of Environmental Health Sciences (NIEHS)

Principal Areas of Focus

The Department of Health and Human Services supports a broad portfolio of research related to environmental health and the health effects of global change. Included in the U.S. Climate Change Science Program is research supported by the National Institutes of Health (NIH) that focuses on exposure to ultraviolet (UV) and near-UV radiation. The principal objectives of the four NIH institutes supporting this research include an increased understanding of the effects of UV and near-UV radiation exposure on target organs (e.g., eyes, skin, immune system), the molecular changes and genetic susceptibilities that lead to these effects, and the development of strategies to prevent the initiation or promotion of disease before it is clinically defined.

In addition to UV and near-UV radiation research, HHS also supports other research related to the health effects of global change. For example, the National Institute of Environmental Health Sciences (NIEHS) supports research on the health effects of (1) air pollution and temperature, (2) agricultural chemicals, and (3) materials used in new technologies to mitigate or adapt to climate change. In addition, the Centers for Disease Control and Prevention (CDC) is engaged in a number of activities related to climate change, such as emerging and reemerging infectious diseases. Such related research is growing in importance.

Program Highlights for FY 2006

The NIEHS program supports grants and intramural projects that investigate the effects of UV exposure on the immune system, aging process, sensitive tissues such as the retina and skin, and methods to reduce these harmful effects. Examples of research include projects that will characterize the DNA damaging and mutagenic properties of UV-A radiation, a component of the solar spectrum that has been linked to melanoma, then attempt to find a molecular link between exposure to sunlight and melanoma.

The National Toxicology Program (NTP) funded and operated by NIEHS is carrying out a systematic analysis of commercially available sunscreens to characterize several nanoscale metal oxides (e.g., titanium, zinc) currently used with regard to their dermal penetration and photocatalytic action. Careful attention is being paid to determining critical aspects of size, surface area and chemistry, crystallinity, and biopersistence in relation to both dermal penetration and potential for toxicity in the presence or absence of simulated solar light.

The National Eye Institute (NEI) supports studies on the impacts of UV radiation on the eye (retinal damage as well as corneal capacity). A major initiative is underway to determine how and why eye

cataract develops and to search for ways to prevent or slow the progression of cataract, an age-related eye disease that affects 17-20 million people globally. This project is investigating the role of UV-B radiation, which has been implicated as a specific risk factor in cataract development. Another important area of research is the understanding of certain detoxification systems in the eye and how they combat damage from UV-B radiation. The goal of this effort is to identify drugs that might have therapeutic or preventative applications. One study is investigating how corneal epithelial cells prevent damage to their DNA by reactive oxygen species generated by UV light and whether the protection against damage provided by nuclear ferritin in corneal epithelial cells can be extended to other cell types in which reactive oxygen species may have deleterious effects.

The National Cancer Institute (NCI) is supporting a wide range of studies to characterize the etiology, biology, immunology, and pathology of a variety of changes in the skin (morphological effects that might precede skin cancer), including photoaging, non-melanoma skin cancers, and melanoma caused by exposure to UV radiation. In addition, NCI is supporting studies to reduce the risk of melanoma and non-melanoma skin cancer through the development of clinically useful primary and secondary prevention strategies. One study is developing, implementing, and evaluating solar protection programs for middle school children. The interventions target school, community, recreation and beach settings, primary care practices, and parents. The interventions are based on theories that include social influence, psychological factors and cognitive decisional factors in adolescence. Other studies are looking at the role of UV light exposure in the development of second malignant neoplasms in cancer survivors.

The National Institute of Arthritis, Musculoskeletal, and Skin Diseases (NIAMS) supports basic and clinical research on the effects of UV-A and UV-B radiation on skin. Examples of studies include research on the role of overexposure to UV light in the development and exacerbation of vitiligo, a pigmentary disorder that leaves patients with disfiguring white skin patches that increase in size over time. Another patient-oriented research project is studying the molecular mechanisms for the exaggerated response to UV-B of a polymorphism that is strongly associated with a photosensitive form of lupus erythematosus. Another study continues work on the effect of UV-R on Langerhans cells, star-shaped cells in the germinative layer of the epidermis, and on immunity in skin. Using Gene Array technology, scientists have identified 52 genes that are consistently up-regulated by UV-R. In the next 5 years, they plan to study the extent to which signaling pathways mediate UV-induced alterations in Langerhans cell function. Other studies are targeted toward understanding the molecular mechanisms of cell replication in maintaining genomic fidelity in the presence of DNA-damaging agents such as UV-B.

Related Research

Renewed concern about emerging and reemerging infectious diseases has prompted increased attention to a variety of insect and tick-borne diseases whose incidence would be affected by environmental change. One area of research, conducted by CDC, is the use of remote sensing to study ecologic systems relevant to transmission of specific infectious diseases, especially vector-borne diseases. Examples of research by CDC using remote-sensing and other geographic/spatial technologies include studies of hantavirus, plague, and Chagas disease. Sin Nombre virus, carried by the deer mouse, causes hantavirus pulmonary syndrome (HPS) in the Americas. Since 1994, CDC has collaborated with local academic institutions to study the effect of climatic variation, such as that associated with El Niño Southern Oscillation (ENSO), on changes in population densities of deer mice. The goal of the U.S.-based studies

is to develop a model using satellite imagery to predict increases in risk of HPS at specific locations across the western United States. These studies have already helped CDC predict and post warnings of increased disease risk in the southwestern United States in 1998 and 1999. Funding will allow part of this study to continue through the end of FY 2006.

A CDC-sponsored study of plague in the four corners area of the U.S. Southwest also employs remote-sensing technology to develop a predictive model for increased plague transmission in the area. Finally, CDC is applying GIS and ecological niche analysis using GARP (Genetic Algorithm for Rule Set Prediction), a form of spatial/temporal analysis, to study the eco-epidemiology of Chagas disease in Guatemala, Mexico, Brazil, and Argentina, and to improve collaborative efforts aimed at disease surveillance and control in these regions.

CDC also sponsors broader research related to climate change and infectious diseases. CDC's Division of Vector-Borne Infectious Diseases is currently collaborating on studies of how the transmission of vector-borne diseases may be affected by the environment. Its Guatemala field station is studying the impact that adverse climatological events, such as El Niño and Hurricane Gilbert, have had on the transmission dynamics of malaria and other diseases. These catastrophic events create tremendous changes that can simultaneously create new vector habit, reduce the levels of sanitation, and overwhelm the ability of the public health system to respond. Other CDC units are collaborating on studies of the effects of climate change on dengue on the U.S.-Mexico Border.

DEPARTMENT OF THE INTERIOR / U.S. GEOLOGICAL SURVEY

Principal Areas of Focus

DOI/USGS research contributes directly to CCSP strategic goals, principally through studies designed to understand the interactions between climate, earth surface processes, and ecosystems on time scales ranging from years to millennia. By combining the expertise of hydrologists, geologists, biologists, geographers, and remote-sensing scientists within one organization, USGS supports truly interdisciplinary research in the following major focus areas:

- Studies of climate history and impacts on landscapes and ecosystems
- Hydrologic impacts of climate change
- Carbon cycle science
- Land-use and land-cover changes
- Decision support research and development.

The goal of global change research at USGS is to improve knowledge and understanding of the Earth's past and present climate and environment, the forces bringing about changes in the Earth's climate, and the sensitivity and adaptability of natural and managed ecosystems to climate changes.

Program Highlights for FY 2006

Earth Surface Dynamics

The Earth Surface Dynamics program has the following research objectives:

- Document the nature of climatic and environmental change and variability on time scales ranging from years to millennia.
- Develop fundamental understanding of interactions between climate, earth surface processes, and marine and terrestrial ecosystems on time scales ranging from years to millennia.
- Seek to understand impacts of climate change and variability on landscapes and marine and terrestrial systems.
- Model and anticipate the effects of climate change and variability on natural and human systems.
- Provide information on the relative sensitivity, adaptability, and vulnerability of ecosystems, resources, and regions to climatic change and variability to support land and resource management and policy decisions.

Geographic Analysis and Monitoring

Research is directed to the understanding of the rates, causes, and consequences of landscape change over time. This knowledge is used to model processes of landscape change and to forecast future conditions. Studies are designed to document and understand the nature and causes of changes occurring on the land surface; to assess the impacts of land surface changes (including urbanization) on ecosystems, climate variability, biogeochemical cycles, hydrology, and human health; and to develop the best methods to incorporate science findings in the decisionmaking process.

Hydroclimatology

Research on effects of climate change and variability on the hydrologic cycle focuses on characterizing, and developing predictive methods related to, the hydroclimatology of North America. This includes identification of seasonal variations in regional streamflow in relation to atmospheric circulation (for regional streamflow prediction and flood/drought hazard assessment); the linkage between atmospheric circulation and snowpack accumulation (for forecasting spring and summer water supply in the western United States and for flood forecasting), as well as glacier mass balance; and the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions (to discriminate natural from human-induced effects on such systems). It also includes documenting the long-term behavior of hydrologic systems in response to past climatic variations and changes (from decades to hundreds of thousands of years) as well as more recent (decadal) hydrologic trends. The program maintains an active effort to develop improved representations of terrestrial hydrologic processes in general circulation and regional climate models. In broad terms, these activities are aimed at improving statistical and deterministic methods for predicting hydrologic hazards and related environmental conditions on monthly to interannual time scales.

Carbon Cycle

USGS conducts a broad range of carbon cycle research focused on North America, which includes:

- *Assessment of Carbon Stocks and Soil Attributes*—Determining the spatial distribution of carbon in the terrestrial environment in relation to historical natural and human processes, as a basis for initializing dynamic models of soil carbon. Measuring soil chemistry has focused on the Mississippi and Delaware River basins, the latter in collaboration with the USDA Forest Service Forest Inventory and Analysis Program.
- *Carbon Sequestration in Sediments*—Studying the re-deposition of eroded soils and sediments (and their associated organic carbon) which sequesters large quantities of carbon, buried at the base of slopes and in wetlands, riparian areas, and reservoirs.
- *Carbon Sequestration in Wetlands*—Field and laboratory process studies, spatial analysis, and modeling are being used in wetlands of the Lower Mississippi River Valley and the Prairie Pothole Region to quantify the influence of land-use change on carbon sequestration and greenhouse gas emissions and to identify environmental factors controlling carbon sequestration. These studies will provide recommendations and decision support tools to resource managers to maximize carbon sequestration benefits consistent with DOI goals for restoration of ecosystem services such as habitat, flood storage, and water quality.
- *Landscape Dynamics and Vegetation Change*—Examining the long-term dynamics of vegetation change in relation to climate change and variability. A detailed history of vegetation change in the western United States is being constructed. Past changes are used to model vegetation response to climatic variables. This knowledge is applied in forecasting the effects of future climate change on the distribution of vegetation in the western United States.
- *Fate of Carbon in Alaskan Landscapes*—Expanding process studies and modeling to better understand both the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration. Cold region forests (boreal ecosystems) contain large carbon reserves that are highly susceptible to changes in climate.
- *Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface*—Employs field measurements, remote sensing, and modeling of carbon fluxes to develop estimates of gross primary productivity, respiration, and net ecosystem exchange at flux tower sites, and uses remotely sensed data to extrapolate these carbon fluxes to ecoregions.

Changes in Ecosystems

USGS global change research on ecosystems aims to determine the sensitivity and response of ecosystems and ecological processes to environmental factors, including existing climate and natural and anthropogenic impacts, at the local, landscape, regional, and continental level; to assess and predict how future environmental conditions may affect the structure, function, and long-term viability of natural and human-impacted ecosystems; and to provide scientific knowledge and technologies needed for conservation, rehabilitation, and management of sustainable ecosystems. Current USGS ecosystems research focuses on:

- The relative sensitivity of biological resources and geographic areas of the Nation to global changes in order to detect early changes and prioritize action
- The causal mechanisms underlying ecosystem responses to global change
- The role of scaling in understanding and managing the spatial and temporal responses of biological systems to global change
- Development and testing of management options for adapting to the effects of global change and minimizing undesired effects of global change.

Satellite Data Management and Dissemination

USGS operates and continually enhances the capabilities of the Center for Earth Resources Observation System (EROS) to serve as the National Satellite Land Remote-Sensing Data Archive, by maintaining existing data sets, adding new ones, and converting older data sets from deteriorating media to modern, stable media. The archive's holdings are used for environmental research, land management, natural hazard analysis, and natural resource management and development with applications that extend well beyond U.S. borders. The worldwide community of archive users includes personnel in Federal, State, local, and tribal governments, researchers at academic institutions, private enterprise, and the public.

Land Use and Land Cover

The Land Cover Characterization Program was started in 1995, to address national and international requirements for land-cover data that were becoming increasingly sophisticated and diverse. The goal is to be a national and international center for excellence in land-cover characterization, via:

- Development of state-of-the-art multiscale land-cover characteristics databases used by scientists, resource managers, planners, and educators (global and national land cover)
- Contribution to the understanding of the patterns, characteristics, and dynamics of land cover across the Nation and the Earth (urban dynamics and land-cover trends)
- Pursuit of research that improves the utility and efficiency of large-area land-cover characterization and land-cover characteristics databases
- Serving as a central facility (Land Cover Applications Center) for access to, or information about, land-cover data.

Related Research

DOI also sponsors contributing research programs addressing the collection, maintenance, analysis, and interpretation of short- and long-term land, water, biological, and other geological and biological processes and resources through dispersed observing networks; research in land use and land cover, including creation of maps and digital data products; and inventorying and monitoring of biological habitats, resources, and diversity.

DEPARTMENT OF STATE

Principal Areas of Focus

Through DOS annual funding, the United States is the world's leading financial contributor to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Intergovernmental Panel on Climate Change (IPCC), the principal international organization for the assessment of scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. Recent DOS contributions to these organizations provide substantial support for global climate observation and assessment activities in developing countries. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral climate change initiatives, including: the Carbon Sequestration Leadership Forum, the Group on Earth Observations, the Methane-to-Markets Partnership, the International Partnership for a Hydrogen Economy, and the Generation IV International Forum.

Program Highlights for FY 2006

During FY 2006, DOS will continue to support the activities of the UNFCCC and the IPCC, including development of the IPCC *Fourth Assessment Report*, and will advance the bilateral and multilateral partnerships for global climate science, technology, and observation that were undertaken in the FY 2004-2005 time frame.

DEPARTMENT OF TRANSPORTATION

Principal Areas of Focus

DOT uses existing science to improve decisionmaking tools in four primary areas. First, DOT is examining the potential impacts of climate variability and change on transportation, which includes research to examine the effects that climate change and variability may have on transportation infrastructure and services. Second, DOT supports research to increase energy efficiency and reduce greenhouse gases. Third, DOT supports efforts to improve transportation greenhouse gas data and modeling. Finally, in a new area of emphasis, DOT may consider institutional capacity issues that support the implementation of multimodal and intersectoral greenhouse gas emission reduction strategies.

Program Highlights for FY 2006

DOT's virtual Center for Climate Change and Environmental Forecasting is undertaking several new research projects expected to be completed in FY 2006:

- *Workshop on Impacts of Global Climate Change on Hydraulics and Hydrology and Transportation*—A partnership with North Carolina State University to consider guidelines for adapting to the potential consequences of climate change.
- *Reducing the Greenhouse Gas and Air Quality Impacts of Freight Transportation*—Identify measures to lower greenhouse gas emissions from freight.
- *Assessing Greenhouse Gas Emissions Benefits of Heavy-Duty Natural Gas Vehicles in the United States*—Improve the understanding of the greenhouse gas emissions reduction potential of heavy-duty natural gas and diesel vehicles by evaluating emissions data from a previously untapped data source at West Virginia University.
- *Assessing State Long-Range Transportation Planning Initiatives in the Northeast for Climate Energy Efficiency Benefits*—Identify tools and methodologies to help northeastern States reduce greenhouse gas emissions through the long-range planning process.
- *Total Fuel Cycle Emissions for Marine Transportation: Development of a "Well-to-Hull" Modeling Tool*—Develop a "well-to-hull" fuel cycle emissions modeling tool for marine transportation.
- *Feasibility of Utilizing the National Energy Modeling System (NEMS) as a Broad Integrating Framework for Greenhouse Gas Emissions Modeling in the Transportation Sector*—Investigate the feasibility of integrating NEMS with other models to enhance the analytical capabilities beyond those of any individual model.

The DOT Center for Climate Change and Environmental Forecasting has initiated Phase I of CCSP Synthesis and Assessment Product 4.7, *Impacts of Climate Variability and Change on Transportation Systems and Infrastructure–Gulf Coast Study*. This project, initiated under the President's Climate Change Research Initiative, is a joint research effort with USGS. The first phase will provide an integrated overview of relative infrastructure sensitivities in the region.

The Federal Aviation Administration (FAA) has a number of ongoing efforts to improve the modeling of aviation emissions of all kinds, including greenhouse gases. The Office of the Secretary is funding several projects to improve the relationship between transportation and climate change, including a *Best*

Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation. The Guidebook will be designed for use by companies and individual operators.

Related Research

Many of DOT's programs have ancillary climate benefits. The Road Weather Management Program—within the Federal Highway Administration's Office of Operations—seeks to better understand the impacts of weather on roadways. The Corporate Average Fuel Economy Program seeks to reduce energy consumption by increasing the fuel economy of cars and light trucks. FAA has a number of ongoing operational and research initiatives that will help reduce the amount of greenhouse gases produced by aviation in the United States and internationally. DOT's funding programs for congestion mitigation, hydrogen-powered transportation, air quality improvement, and transit developments all reduce emissions, including greenhouse gases.

AGENCY FOR INTERNATIONAL DEVELOPMENT

Principal Areas of Focus

The Famine Early Warning System Network (FEWS NET) is an innovative application of science to efforts to alleviate risks related to existing climate variability or the potential for climate change. Through FEWS NET, USAID provides decisionmakers—both in the United States and in other parts of the world—with information designed to inform decisions that more effectively respond to drought and food insecurity. In the past, FEWS NET focused activities in 18 drought-prone countries across Sub-Saharan Africa. As of 2003, FEWS NET began expanding coverage to selected countries of Asia and Latin America and the Caribbean. In addition to monitoring a wide variety of socioeconomic indicators to identify levels of food insecurity, FEWS NET monitors and analyzes remotely sensed data and ground-based meteorological, crop, and rangeland observations to track the progress of rainy seasons and crop production in semi-arid regions, in order to identify early indications of reduced food availability and access.

Program Highlights for FY 2006

In FY 2006, FEWS NET will continue to provide seasonal monitoring in relationship to analyses of food insecurity conditions in 20 countries in Africa and three countries in Central America, as well as in Haiti and Afghanistan. A major element of this work is strengthening information networks that collect and analyze data to reveal intra- and interannual weather variability trends as they relate to longer term climate variability.

ENVIRONMENTAL PROTECTION AGENCY

Principal Areas of Focus

EPA's Global Change Research Program has its primary emphasis on evaluating the potential consequences of global change (particularly climate variability and change) on air quality, water quality, ecosystems, and human health in the United States. This includes improving the scientific basis for evaluating effects of global change in the context of other stressors, and evaluating the risks and opportunities presented by global change. EPA uses the results of these studies to investigate adaptation options to improve society's ability to effectively respond to the risks and opportunities presented by global change. The program is multidisciplinary and emphasizes the integration of the concepts, methods, and results of the physical, biological, and social sciences into decision support frameworks. This work is consistent with and closely coordinated with the *CCSP Strategic Plan*.

The planning and implementation of EPA's program is integrated by the CCSP with other participating Federal departments and agencies to reduce overlaps, identify and fill programmatic gaps, and add value to products and deliverables produced under the CCSP's auspices. EPA coordinates with other CCSP agencies to develop and provide timely, useful, and scientifically sound information to decisionmakers. This includes support for the production of CCSP synthesis and assessment products called for in the *CCSP Strategic Plan*, and the development of decision support tools for resource managers and decisionmakers. Also, as called for by the National Research Council in 2001, EPA supports and fosters projects that link knowledge producers and users in a dialog that builds a mutual understanding of what is needed, what can credibly be said, and how it can be said in a way that maintains scientific credibility.

EPA's program also makes significant contributions to the high-level interagency bilateral climate dialogs that are led by the Department of State. EPA's program supports research on climate impacts and adaptation in China, Italy, Canada, and India. These activities focus on evaluating the potential consequences of climate change and adaptation strategies.

EPA's program has four areas of emphasis: air quality, water quality, ecosystems, and human health. The results of studies done in these areas are integrated at particular places (such as watersheds).

Air Quality

Few studies have investigated the effect of global change on air quality. Studies are planned that will examine the potential consequences of global change on air quality in the United States. The long-term goal of this focus area is to provide the approaches, methods, and models to quantitatively evaluate the potential effects of global change on air quality, and to identify technology advancements and adaptive responses and quantify their effect on air quality.

Water Quality

Water quality is affected by changes in runoff following changes in precipitation and evapotranspiration and/or changes in land use. The program is investigating the possible impacts of global change (climate and land-use change) on water quality using a watershed approach. The water quality studies will contribute to and benefit from human health and ecosystems studies.

Ecosystems

EPA's mission is not only to protect human health but also to safeguard the natural environment. EPA provides environmental protection that contributes to making communities and ecosystems diverse, sustainable, and economically productive. Consistent with this goal, EPA's Global Change Research Program has planned three research activities that evaluate the effects of global change on aquatic ecosystems (which include lakes, rivers, and streams; wetlands; and estuaries and coastal ecosystems), invasive nonindigenous species, and ecosystem services. EPA's investigations of the effects of global change on aquatic ecosystems will use as input the research being done by other CCSP agencies on marine and terrestrial ecosystems. Therefore, EPA's ability to successfully complete its assessments depends crucially upon the ability of other CCSP agencies to complete their related research activities.

Human Health

Since health is affected by a variety of social, economic, political, environmental, and technological factors, investigating the potential health impacts of global change is a complex challenge. As a result, health studies in EPA's Global Change Research Program go beyond basic epidemiological research to develop integrated health evaluation frameworks that consider the effects of multiple stresses, their interactions, and human adaptive responses. Along with health sector studies conducted in conjunction with other CCSP agencies, there are research activities focused on the possible consequences of global change on weather-related morbidity and vector- and water-borne diseases. In addition, the results from air quality studies will be used to evaluate health consequences.

Intramural and extramural research contribute to all of EPA's investigations. In an attempt to capitalize on expertise in the academic community, a significant portion of the program's resources is dedicated to extramural research grants administered through the Science to Achieve Results (STAR) program. The STAR program focuses on science to support investigations of the consequences of global change for air quality, ecosystems, and human health in the United States. EPA will continue to coordinate closely with other CCSP agencies doing human dimensions research to identify the specific topics that should be emphasized within the STAR program.

Program Highlights for FY 2006

EPA will continue to make significant contributions to the ongoing research activities of the CCSP. EPA strives to understand relative risks in the context of multiple stressors, at multiple scales and multiple levels of biological and institutional organization. EPA-sponsored investigations will continue to be conducted through public-private partnerships that actively engage researchers from the academic community, decisionmakers, resource managers, and other affected stakeholders. Highlights of specific activities that will be undertaken by EPA in FY 2006 follow:

- Support the CCSP commitment to generate 21 synthesis and assessment products by leading or co-leading three analyses and supporting seven others.
- Support the high-level interagency bilateral climate dialogs with China, Italy, Canada, and India that are being led by the Department of State.
- Produce a report that identifies those threatened and endangered species that may be at greater risk from climate change.
- Evaluate the effects of climate-related stressors on coral reef ecosystems. Research will be conducted in American Samoa and the Florida Keys.

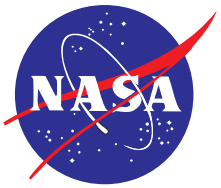
- Study the management implications of global change and interacting stressors on the establishment and expansion of invasive species.
- Conduct case studies of climate change effects on bioindicators and biocriteria programs.
- Investigate the effects of changes in climate and land use on non-point source pollution in estuaries.
- Study current land conservation practices and provide a tool for projecting future distributions of land protection as a climate change adaptation mechanism to restore or maintain ecosystem services.
- Produce a report that examines the possible implications of global change for combined sewer overflow events.
- Develop a synthesis report detailing the health effects of airborne allergens associated with climate change.

Related Research

In addition to focused CCSP activities, EPA conducts research that contributes to the characterization and understanding of risks to ecosystems and to human health. The ecosystems-based research is designed to understand and predict ecosystem exposure, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors (e.g., invasive species, genetically altered organisms) at multiple scales of biological organization and geographic scales. The research in human health is oriented toward assessing the cumulative health risks to humans (e.g., cancer, reproductive, cardiovascular)—including high-risk subpopulations (e.g., children)—from chemical stressors emanating from multiple sources. Both of these major research areas can be affected by climate change.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Principal Areas of Focus



NASA's Earth science programs are essential to the implementation of three major Presidential initiatives: Climate Change Research (June 2001), Global Earth Observation (July 2003), and Ocean Action (December 2004). The first is the subject of the Climate Change Science Program and this document. The second is related, and focuses on national and international coordination of Earth observing capabilities to enhance their use in meeting important societal needs. The third uses NASA's observing technologies and knowledge of Earth as a system to advance ocean research and applications with partner agencies.

NASA Earth science programs are aimed at understanding the Earth system and applying Earth system science to improve prediction of climate, weather, and natural hazards in partnership with other Federal agencies and international space and research programs. NASA's *Research Strategy* orchestrates observing and modeling programs to address the question "How is the Earth changing, and what are the consequences for life on Earth?" Five subordinate questions describe NASA's Earth system science approach via a paradigm of variability, forcing, response, consequence, and prediction:

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced change?
- What are the consequences of change in the Earth system for human civilization?
- How well can we predict future changes in the Earth system?

NASA's portfolio includes observations, research, analysis, modeling, and advanced technology development, in order to answer selected science questions, and benchmarking decision support resources to ensure society receives the benefits of this research.

NASA pioneered the interdisciplinary field of Earth system science, which explores the interaction among land, oceans, atmosphere, ice, and life. To study these interactions, NASA has developed and deployed the Earth Observing System (EOS) and related satellites, and suborbital and surface-based sensors—collecting, processing, archiving, and distributing these data through the EOS Data and Information System (EOSDIS). EOSDIS is the largest "e-science" system in the world. In 2004, EOSDIS was accessed by over 2 million distinct users, with over 200,000 users receiving 34 million data products. Following the Earth system science construct, NASA has organized its research into six science focus areas. The table on the facing page identifies these six areas and how they align with the CCSP research elements.

Program Highlights for FY 2006

In FY 2006, NASA will make significant progress in three high-priority CCSP research areas: aerosols, carbon, and polar regions. NASA will begin routine acquisition and analysis of data on the three-dimensional structure of clouds and aerosols in the atmosphere from the Cloudsat and Calipso satellites. NASA will continue to be a leader in the North American Carbon Program (NACP), contributing to

CCSP RESEARCH ELEMENTS	NASA EARTH SCIENCE FOCUS AREAS
Atmospheric Composition	Atmospheric Composition
Climate Variability and Change	Climate Variability and Change
Global Water Cycle	Global Water and Energy Cycle
Land-Use/Land-Cover Change Global Carbon Cycle Ecosystems	Carbon Cycle and Ecosystems
Human Contributions and Responses	
	Weather
	Earth Surface and Interior

the observations, field campaigns and experiments, and model development needed to reduce scientific uncertainties of carbon sources and sinks in North America. NASA will continue development and scientific preparations for space-based measurements of global atmospheric carbon to detect global carbon dioxide sources and sinks worldwide. NASA will continue to develop new ways to measure sea-ice thickness using ICEsat data and new innovative instrumentation currently under development. NASA will develop new observations and models of other critical polar processes to better understand their behavior and interactions with global climate.

NASA will implement a recently restructured computational Earth system modeling program through an open, competitive process to focus its efforts on the key science challenges of the decade ahead. NASA will also implement computational modeling efforts, selected through similar competitive processes, to exploit its new Project Columbia—the second largest supercomputing cluster in the world (behind IBM's Blue Gene).

In FY 2006, NASA will make further strides in enhancing Earth observation and monitoring. NASA and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office will complete development of the NPOESS Preparatory Project Mission for launch in early FY 2007. This satellite mission will extend key measurements from NASA's Terra and Aqua satellites as well as demonstrate new remote-sensing instruments for NPOESS. Following the path of Cloudsat and Calipso, three new satellites will be under development to observe atmospheric carbon dioxide, global ocean surface salinity, and global soil moisture. NASA will continue its work through the Interagency Working Group on Earth Observations to transition responsibilities for mature measurements to operational systems to assure long-term data continuity.

Related Research

NASA's other science focus areas (Weather, Earth Surface and Interior, and Sun-Earth Connection) seek to understand and predict Earth system change. The NASA-sponsored Socio-Economic Data Center

(SEDAC) archives and distributes data used in CCSP's Human Dimensions research area. NASA also manages an Earth Science Applications program in partnership with other Federal agencies, State and local governments, academia, and industry to test new uses of remote-sensing data to solve practical societal problems in twelve applications of national priority:

National Application	Partner Agencies
Renewable Energy	DOE, EPA
Agricultural Efficiency	USDA, EPA
Carbon Management	USDA, EPA, DOE, USGS, USAID
Aviation	DOT/Federal Aviation Administration
Homeland Security	Department of Homeland Security, National Governors Association, USDA, USGS, NOAA, DOD
Ecological Forecasting	USGS, USDA, USAID
Disaster Preparedness	Federal Emergency Management Agency, USGS, NOAA, USDA
Public Health	Centers for Disease Control, DOD, NIH, EPA, USGS, NOAA
Coastal Management	NOAA, EPA
Invasive Species	USGS, USDA
Water Management	Bureau of Reclamation, USGS, EPA, USDA
Air Quality	EPA, NOAA, USDA, DOT/Federal Aviation Administration

NATIONAL SCIENCE FOUNDATION

Principal Areas of Focus

NSF programs address global change issues through investments in challenging ideas, creative people, and effective tools. In particular, NSF global change research programs support research and related activities to advance the fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary activities and focus particularly on Earth system processes and the consequences of change. NSF programs facilitate data acquisition and information management activities necessary for fundamental research on global change, and promote the enhancement of models designed to improve understanding of Earth system processes and interactions, and to develop advanced analytic methods to facilitate basic research. NSF also supports fundamental research on the general processes used by organizations to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of varying environmental conditions. Through its investment, NSF contributes to CCSP by providing a comprehensive scientific foundation for many of the synthesis and analysis products identified in the *CCSP Strategic Plan*.

Program Highlights for FY 2006

Atmospheric Composition

NSF programs in tropospheric and stratospheric chemistry will continue to address the composition of the atmosphere and its relation to climate variability and change. Studies of the transformation and transport of gaseous constituents and aerosols provide insights into the radiative and cloud nucleating properties of the atmosphere. Studies of the global distributions of greenhouse gases will provide input for future scenarios of radiative forcing.

Climate Variability and Change

NSF programs continue to emphasize climate variability and change as a major issue. This research element supports observational campaigns and numerous analytical and modeling activities. Ocean science efforts will focus on changes in ocean structure, circulation, and interactions with the atmosphere to improve our current understanding of the processes and models that address future changes, particularly those that may happen abruptly. Major support will continue to permit the Community Climate System Model to improve model physics and parameterizations that will lead to more comprehensive models incorporating interactive chemistry and biology. Studies of paleoclimatology will continue to be supported as a means to provide baseline data on natural climate variability from the past and from key climatic regions. These studies will improve our understanding of the natural variability of the climate system and in particular will enable reconstructions and evaluations of past environmental change as inputs for model validations.

The Global Water Cycle

NSF supports a broad-based effort to understand all aspects of the global water cycle. Relevant programs will continue to explore ways to optimally and effectively utilize the wide range of hydrological data types—continuous and discrete time and space information from a variety of platforms for research purposes. Information from process studies will be used to refine models through scaling and parameterizations of sub-grid processes, particularly the fluxes of water through the Earth system. Planning for and the initiation of several prototype hydrologic observatories, both physical and virtual,

are being carried out. Science and Technology Centers will continue to work with stakeholders responsible for water management and with educators to translate research advances into useful products, particularly exploring issues related to decisionmaking in the face of uncertainty as applied to the urbanizing and drought-prone Southwest.

Land-Use and Land-Cover Change

Several NSF programs continue to address key aspects of land-use and land-cover change through studies in ecological rates of change and related species diversity; Arctic systems; temporal variability; water and energy influences on vegetative systems; and diverse human influences on land utilization.

Global Carbon Cycle

NSF supports a wide variety of carbon cycle research activities. Investigations examine a range of topics in terrestrial and marine ecosystems and their relations to the carbon cycle. Research in terrestrial settings will explore, for example, carbon storage, delivery of carbon by rivers, carbon fluxes from high-latitude soils, and carbon export from mountains and submarine groundwater discharge. In the oceans, clathrate stability, abiotic carbon cycling, and the upper ocean carbon budget will be addressed. Carbon cycle studies will integrate observational data into models to provide insights for understanding key aspects of the global carbon cycle.

Ecosystems

Several NSF programs address terrestrial and marine ecosystems through observational, experimental, modeling, and laboratory studies. The collection of ecosystem data in terrestrial and marine systems through the Long-Term Ecological Research (LTER) projects provide a major source of information. The Global Ocean Ecosystem Dynamics program will continue to study the impact of global ocean changes on marine ecosystems through specific synthesis activities focused on the North Atlantic and the North Pacific.

Human Contributions and Responses

NSF supports basic research on the processes through which people (individually, in groups, or through organizations) interact with natural environmental systems. Programs support projects that focus on decisionmaking under uncertainty associated with climate change. These projects are expected to produce new knowledge and tools that should facilitate improved decisionmaking by various stakeholder groups trying to deal with uncertainties associated with future climate variability and change.

Related Research

NSF will continue to support "contributing" research on broader topics that are closely related to global and climate change. These include, *inter alia*, studies of the atmosphere, ocean, land surface, ecosystems, paleoclimatology, and human dimensions, all of which add substantively to the specific programs supporting CCSP objectives. NSF has the computing infrastructure in place and under enhancement to enable more effective utilization of the research information. In addition, NSF supports projects that integrate research with education on global and climate change to demonstrate that scientific visualization—incorporated into inquiry-based learning—can enable students to develop an understanding of complex global change phenomena. Students address these issues by evaluating multimedia data at various spatial and temporal resolutions, reviewing scientific evidence, and considering social concerns that contribute to global and climate change debates.

SMITHSONIAN INSTITUTION

National Air and Space Museum (NASM)
National Museum of Natural History (NMNH)
National Zoological Park (NZP)
Smithsonian Astrophysical Observatory (SAO)
Smithsonian Environmental Research Center (SERC)
Smithsonian Tropical Research Institute (STRI)

Principal Areas of Focus

Within the Smithsonian Institution, global change research is conducted at the Smithsonian Astrophysical Observatory, the National Air and Space Museum, the Smithsonian Environmental Research Center, the National Museum of Natural History, the Smithsonian Tropical Research Institute, and the National Zoological Park. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on daily to decadal time scales, and defining longer term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The Smithsonian Institution program strives to improve knowledge of the natural processes involved in global climate change, to provide a long-term repository of climate-relevant research materials for present and future studies, and to bring this knowledge to various audiences, ranging from scholarly to the lay public. The unique contribution of the Smithsonian Institution is a long-term perspective—for example, undertaking investigations that may require extended study before producing useful results and conducting observations on sufficiently long (e.g., decadal) time scales to resolve human-caused modification of natural variability.

Program Highlights for FY 2006

Atmospheric Composition
At SERC, measurements will be made of spectral UV-B in Maryland (>25-year record), Florida, Arizona, and other sites in the United States. These data will be electronically disseminated to meet the needs for assessing the biological and chemical impact of varying ultraviolet radiation exposures. During FY 2006, results will be used to update trends in surface ultraviolet radiation, and will be reported in national meetings and peer-reviewed publications.

Climate Variability and Change
Research at NASM will emphasize the use of remote-sensing data to improve theories of drought, sand mobility, soil stability, and climate change in the eastern Sahara. Studies at NMNH and STRI will focus on the paleoecology of climate change.

Terrestrial and Marine Ecosystems
Several Smithsonian programs will examine biological responses to global change. At SERC, research will be conducted on the responses of global ecosystems to increasing carbon dioxide concentrations (also a contribution to the Global Carbon Cycle program). A retrospective analysis of the 18-year data set is expected to be completed in FY 2006. This SERC program will also focus on invasive species, and

solar UV-B. Biodiversity education and research will be performed at STRI, NMNH, and NZP. Tropical biodiversity research programs monitor global change effects through repeated sampling of flora and fauna in tropical forests, and identifying the physical and biological processes of growth and decline of species. Other studies on ecosystem response to increasing habitat fragmentation will be conducted at NZP.

Human Dimensions of Global Change

The general public and research community will be informed of global change research conducted by Smithsonian and other CCSP agencies via exhibits. During FY 2006, exhibits developed by staff at NMNH, SERC, and SAO will be displayed at NMNH in the "Forces of Change: Global Links" series concerning the atmosphere and the Arctic, with accompanying educational programs and ancillary information accessible through the internet.

Related Research

Much of the global change research performed at the Smithsonian is not supported by direct Federal appropriation (i.e., CCSP cross-cut funding) and instead is supported by other public and private sources (including other CCSP-participating agencies). These projects are nonetheless organized around the CCSP program elements, thus amplifying the scope and impact of research supported directly by CCSP. At SAO, there are continued studies on the relationship of solar activity and programs that will contribute to global climate observations, enhance climate modeling systems, and reduce scientific uncertainties of aerosol effects. SERC and STRI receive agency support via competitive grants programs to perform studies of ecosystem responses to increased carbon dioxide, UV-B, and invasive species. Other contributing activities include research conducted by several units within the Smithsonian in a variety of habitats concerning natural and human-induced variations in species, populations-communities, and ecosystems. These studies help clarify the relative importance of global change effects as one of several agents of ecological change. Studies of environmental change over long time periods are aided by the Institution's collections. Used by researchers around the world, these materials provide raw data for evaluating changes in the physical and biological environment that occurred before human influences.

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The Climate Change Science Program incorporates the U.S. Global Change Research Program and the Climate Change Research Initiative.

To obtain a copy of this document, place an order at the Global Change Research Information Office (GCRIO) web site: http://www.gcrio.org/orders.

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